GEOCHEMISTRY AND PETROLOGY OF ECLOGITIC ROCKS IN THE FAIRBANKS AREA, ALASKA

A

DISSERTATION

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by

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GEOCHEMISTRY AND PETROLOGY OF ECLOGITIC ROCKS IN THE FAIRBANKS AREA, ALASKA

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ABSTRACT

Eclogites have generally been considered to be compositionally analogous to basic igneous rocks and to have been recrystallized at high temperatures and/or pressures.

A group of eclogitic rocks in the Fairbanks area are new compositional variants and are, together with more orthodox eclogites, an essential unit within a metasedimentary sequence, which has recrystallized under lower amphibolite facies conditions.

Chemical analyses of the unusual calcite-bearing eclogitic rocks strongly suggest that they are derived from sedimentary parents akin to calcareous marls.

The clinopyroxenes from these eclogites are typical omphacites, and the coexistant garnets are typical of garnets from eclogites in blue schist terrane.

Chemical variation diagrams and distribution coefficients of the coexistent mineral phases also indicate that the eclogitic rocks in this study crystallized at low pressures and at moderate temperatures.

Petrographic studies suggest that the temperature of formation of the eclogitic assemblages was between about 570 and 590 degrees centigrade at pressures between 5.5 and 7.5 kilobars. The role of the vaporous products of reactions leading to the eclogitic assemblages is considered to be important in determining the ultimate paragenesis.

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INTRODUCTION

LOCATION AND DESCRIPTION OF THE STUDY AREA

The study area is located approximately 13 miles NNE of Fairbanks, Alaska, between lat. 65 00' and 65 09' N and long. 147 20' and 147 43'W. It is bounded to the northeast and southwest by the Steese and Elliot Highways respectively, and by the Chatanika valley on the northwest (see Fig. 1).

The topography is characterized by low rolling hills with a maximum elevation of 2600' at Pedro Dome. Ready accessibility to the eclogite-bearing terrane is provided by a secondary road network dating from earlier placer and lode gold mining operations.

The area is underlain by crystalline schists of the Birch Creek Basement complex. Structural and lithologic data are difficult to obtain, however, due to heavy vegetative cover and the effects of frost-heaving and solifluction which accompany the Interior Alaska climate. Bedrock exposures were best obtained from road-cuts, prospect-pits, north-facing slopes above 1000' elevation and aqueducts and tailing-piles from the mining operations.

FIELD WORK

The 1:24,000 base used for geologic mapping was enlarged from portions of the Livengood A-1 and A-2 quadrangles. Field work was initiated in the fall of 1967 and completed in the summer of 1969. The geologic map and structure sections compiled from this work are shown in plates 1 through 3.

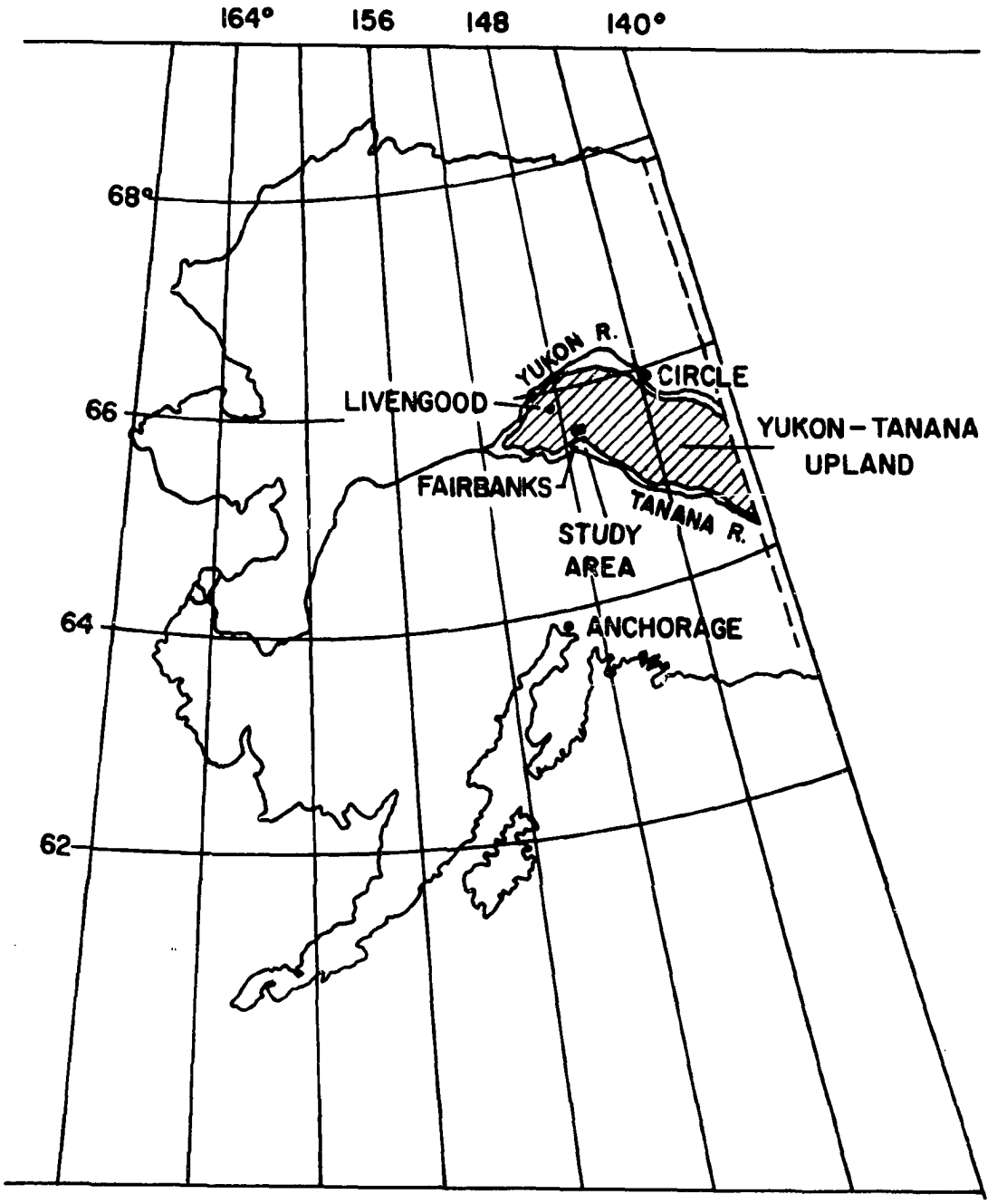


Fig. 1. Location map of the study area.

ANALYTICAL METHODS

After comminution, seiving and washing, mineral separation was effected by a combination of magnetic and sink-float techniques. Heavy liquids used were tetrabromoethane, diiodomethane and Clerici's solution. Hand-picking of the separates achieved 98-99% purity. Splits of these mineral separates were used for all subsequent analyses.

Refractive indices were determined with sodium-D light and oils calibrated to 0.0002. The oils were subsequently checked with a Leitz-Jelly refractometer.

Nickel-filtered Cu K radiation was used in the X-ray diffraction studies of garnet and clinopyroxene, and silicon and A.R. grade NaCl were used as the respective internal standards.

K^{40}/Ar^{40} dating of micas and amphiboles was done by the Geochron Laboratories in Cambridge, Massachusetts.

Chemical analysis of all mineral phases and whole rocks were performed by Hiroshi Haramura under the monitorship of Professor Takahashi Katsura at the Tokyo Institute of Technology.

A computer program for the chemical analyses was written by L. Heiner of the University of Alaska, and a least-squares program for the calculation of lattice-parameters of minerals was adapted by D. Prozesky from an unpublished computer program by D. Schwartzenbach.

PURPOSE OF THE STUDY

Hauy, (1822), proposed the term eclogite for a rock composed essentially of a clinopyroxene rich in the jadeite component and a pyrope-rich garnet.

Since then the term has been extended to similar rocks which also include amphibole, kyanite, zoisite, plagioclase, orthopyroxene, quartz and calcite as accessory or minor phases.

Although Angel, (1957), suggested that all eclogites are chemically analogous with basaltic rocks, Forbes, (1965), presented data which militated against this idea. O'Hara, (1963), has stated:

"It must be concluded that most eclogites which occur as lenses in metamorphic terranes have been introduced there as crystalline masses by tectonic action": -a concept which has been accepted by many petrologists.

Evidence for the metasedimentary origin of some eclogites has been presented by Hahn-Weinheimer, (1959), and Morgan, (1967).

This paper presents data which conclusively show that the eclogites of the Fairbanks area are of sedimentary origin. Field relationships also indicate that the eclogites are in situ units in a polymetamorphosed metasedimentary sequence.

ACKNOWLEDGEMENTS

Sincere gratitude is expressed to the National Science Foundation for the research grant which supported most facets of this project (NSF Research Grant GA 1273). Financial support for the 1968 field work was also contributed by the U.S. Geological Survey Heavy Metals Program (Contract No. 14-08-0001-10919).

Administrative, logistics and technical assistance was tendered by various groups within the Geophysical Institute of the University of Alaska with extreme efficiency throughout the project.

Field, laboratory and personal supervision was always readily available from Dr. R. B. Forbes, who, as thesis advisor and committee chairman facilitated many aspects of the project. I would like to thank him and other members of the faculty of the Geology Department, University of Alaska, especially Drs. D. Ray and D. B. Hawkins for their helpful comments and supervision.

To Mr. H. Haramura and Dr. T. Katsura, whose promptness in the chemical analyses greatly aided the project, and Mr. L. Heiner, who spent many hours on the computer program for the treatment of the analytical data, my warmest thanks.

The base map for the plate #3 was constructed by the members of the summer field camp of the Geology Department in the summer of 1968, and their collective effort was invaluable to the author.

Finally, I offer thanks to the many people who aided the project in many ways, though specific mention has not been made in this paper.

GEOLOGIC SETTING

THE BIRCH CREEK FORMATION

The Birch Creek Formation was named by Spurr, (1898), based on a type-section exposed in the valley of Birch Creek in the Circle District, Yukon-Tanana Uplands, Central Alaska. Mertie, (1937), assigned the Birch Creek schists to the Precambrian after noting that they were more highly recrystallized than the relatively unmetamorphosed pre-Middle Cambrian Tindir group of the Nation River area, north of Eagle. Roddick, (1967), has presented evidence which suggests that the Tindir group north of the Yukon River and the Birch Creek schists to the south are separated by a right-lateral fault, the Tintina Lineament, of some 200 km displacement.

In the Fairbanks district the Birch Creek schists are bounded on the north and south by belts of low grade metamorphic rocks composed of greenschists, slates and argillites which were assigned by Mertie, (1937), to the pre-Middle Ordovician. Stratigraphic and paleontological evidence for this age was observed by Mertie (op.cit.) southeast of the White Mountains, but definitive evidence of such a date has not been found in the southern belt. Relationships between the pre-Middle Ordovician rocks and the Birch Creek schists remain obscure.

THE ECLOGITE-BEARING TERRANE

Previous work

Prindle, (1913), first reported eclogitic rubble in the placer mine-dumps in the vallies of Vault, Dome and Cleary Creeks. He described three distinctive types of eclogitic rocks collected in these vallies and on the intervening ridges.

a) Rocks composed of intercalated carbonate and pale-green pyroxene layers plus ubiquitous garnet, abundant sphene, accessory colourless mica, iron ore and hornblende.

b) A massive variety composed of dark green pyroxene, pale pink garnet and considerable rutile.

c) A massive rock composed of amphibole, garnet, sphene and rutile.

The importance of this discovery was apparently lost in the earlier literature, since no further research was conducted on these rocks until the localities were "rediscovered" in the literature by Forbes and Brown, (1961). Subsequent reconnaissance work by Forbes and Brown (op.cit.) and Brown, (1962), clarified the geology of the area, including the distribution of the eclogite-bearing terrane. Further work showed that the eclogite-bearing schist belt could be traced from the valley of Vault Creek continuously to that of Cleary Creek, (see Plate 1).

Forbes and Brown also noted that two belts of clinopyroxene-bearing calc-magnesian rocks appeared to be located on the northwest and southeast flanks of the "Cleary Anticline", (see Plate 1); and that although the strike of the foliation and compositional layering in the pelitic schists and greenschists along the axis of the anticline strike northeasterly, northwest striking structural trends were also present along the eclogite-bearing belt. Brown, (1962), also noted that the isoclinal recumbent style of the folding around the northwest-trending axes was in sharp discordance with the northeast-trending open and upright folds which are present in the adjacent pelitic terrane.

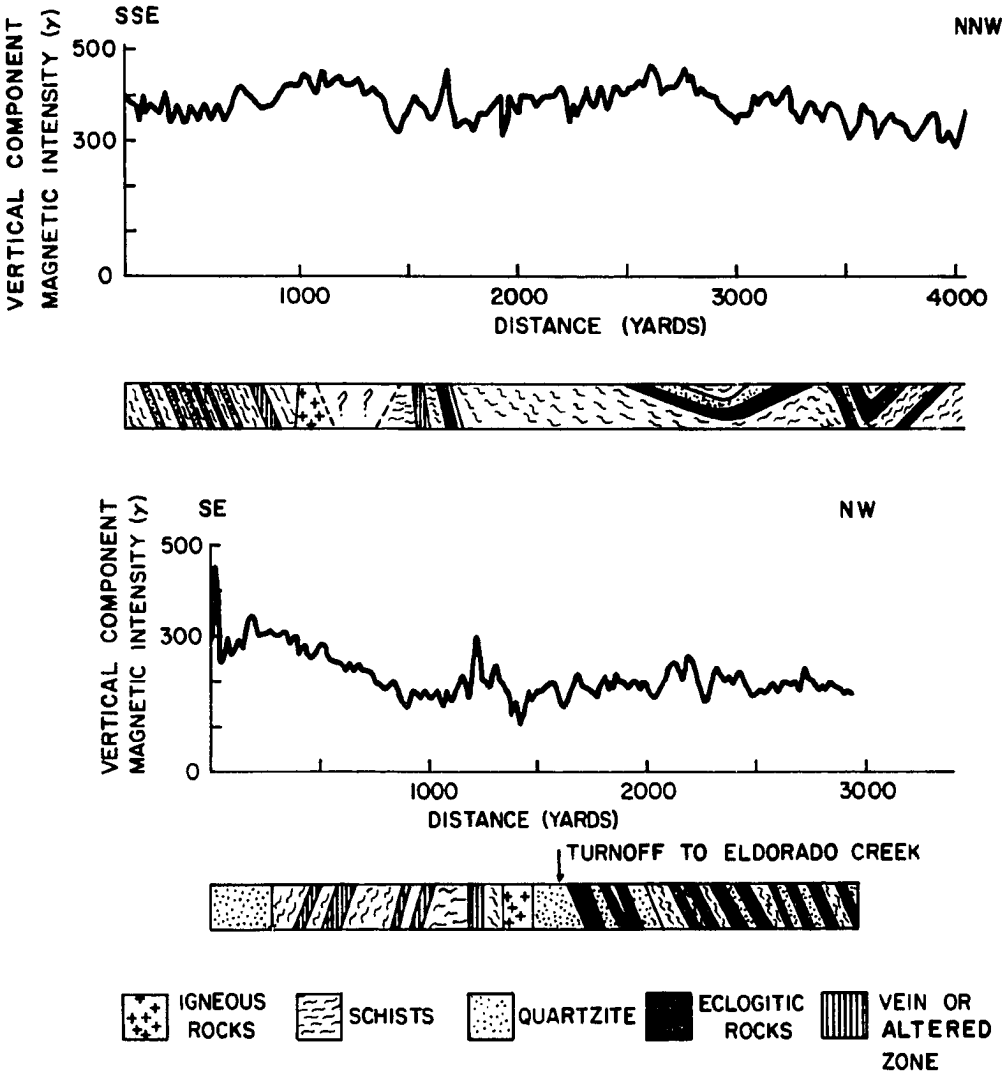
Subsequently Forbes, et.al. (1966) reported on the chemical composition of a representative calc-eclogite and its constituent clinopyroxene. They called attention to the fact that the pyroxene contained 14% of the jadeite molecule, and that the host rocks should be called eclogite even though the compositions were not analogous to basic igneous rocks.

Geophysical data

During the summer of 1968 gravity and magnetic profiles were completed along the Elliot Highway from Fox to Olnes by Mr. Len Anderson of the U.S. Geological Survey and Mr. J. Kinele of the Geophysical Institute, University of Alaska. These profiles show an increase in total magnetic field intensity which coincides with the first observed rubble crop of eclogitic rocks. Two magnetometer traverses made by the author in the summer of 1968 in Dome Creek and on the road between Dome and Eldorado Creeks, Fig. 2, show a significant low immediately before the first observed eclogitic rubble. Variations between rock units within the calc-magnesian terrane are more easily distinguished than variation between the eclogitic rocks and the pelitic schists to the south.

The gravity profile along the Elliot Highway indicates a gradual increase in the density of the rocks composing the section from the pelitic schist to the eclogitic terrane. This effect is thought to be due to the wedging out of the schists towards the eclogitic terrane.

The geophysical data combine to indicate a discontinuity of variable attitude and unknown magnitude defines the southern margin of the eclogite-bearing terrane. South of the discontinuity the pelitic schists have a lower specific gravity, and quite probably have a reduced magnetic susceptibility.



Figs. 2a,2b. Magnetic profiles of the vertical component along Dome Creek - Eldorado Creek road, (above), and in Dome Creek, (below).

Adjacent calc-magnesian schists

Calc-magnesian units are not restricted to the flanks of the "Cleary Anticline" in the area. Marbles and amphibolites also crop out on the valley side near Fox, eight miles south of the study area. Calc-magnesian schists are also present in a sequence of schists which increase in grade from the garnet to the kyanite isograd in a 10,000' borehole at Eielson Air Force Base, about 30 miles south of the study area (Forbes and Weber, in press). In the latter case, however, no reaction is seen between the quartz, calcite and tremolite, which contrasts with the eclogite-bearing terrane of the Cleary region, where clinopyroxene which is produced from similar reactants is a stable mineral phase.

Impure marbles and amphibolites also occur on Chena Ridge and in roadcrops along the new Murphy Dome road between O'Connor and Moose Creeks. Clinopyroxene does not appear in any assemblage in these rocks. Although rocks of appropriate composition are quite widespread, clinopyroxene is found only in the restricted locale of the eclogite-bearing terrane which is discussed in this paper.

LITHOLOGY AND STRUCTURE OF THE ECLOGITE-BEARING TERRANE

ROCK TYPES

The following rock-types are recognized in the field area:-

a) Garnetiferous mica schists, quartz-mica schists and micaceous quartzites.

b) Garnet-clinopyroxene ± (calcite-quartz-"epidote"-plagioclase) rocks.

c) Garnet-clinopyroxene-amphibole ± (calcite-quartz-"epidote"-plagioclase) rocks.

d) Garnet-amphibole ± (calcite-quartz-"epidote"-plagioclase) rocks.

Variants bearing carbonaceous matter of the above, especially a and d, are common in the calc-magnesian terrane. To the south of the eclogite-bearing terrane the pelitic schists contain abundant chlorite, but little garnet; and the amphibolites are not garnetiferous.

Pyroxene-bearing variants are present in the extreme southeast part of the belt, and except in the valley of Dome Creek they can be found along the whole trend, to the last observed outcrop in the Davidson Ditch east of Cleary Creek.

Detailed geologic mapping in a borrow-pit at 6.1 mile on the Elliot Highway (Plate 3) in addition to the data obtained from isolated outcrops throughout the eclogitic terrane shows that the eclogitic rocks occur as conformable lenses and layers within a metasedimentary sequence.

STRUCTURE

The polymetamorphic history of the terrane is seen on a microscopic scale in the refolding of recumbent microfold axes similar to Fig. 4b. Structural analogues have been mapped in the field at all scales.

Fig. 3a. Zoned tourmaline overgrowths on rounded tourmaline nucleii in a pelitic schist, F71.

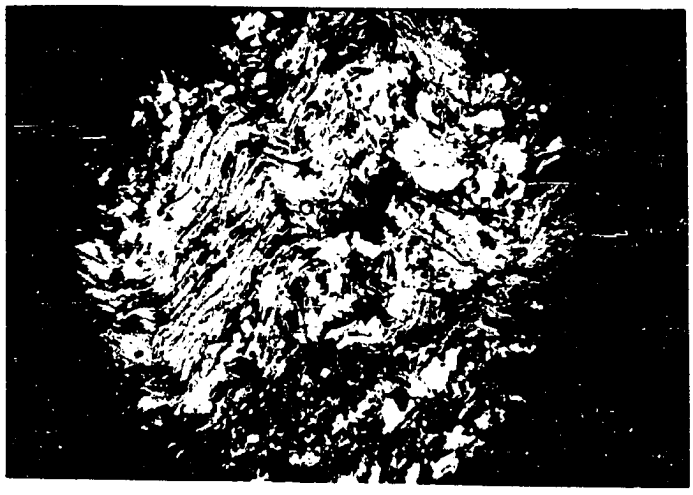


Fig. 3b. Kink-banding in a pelitic schist, F1C.

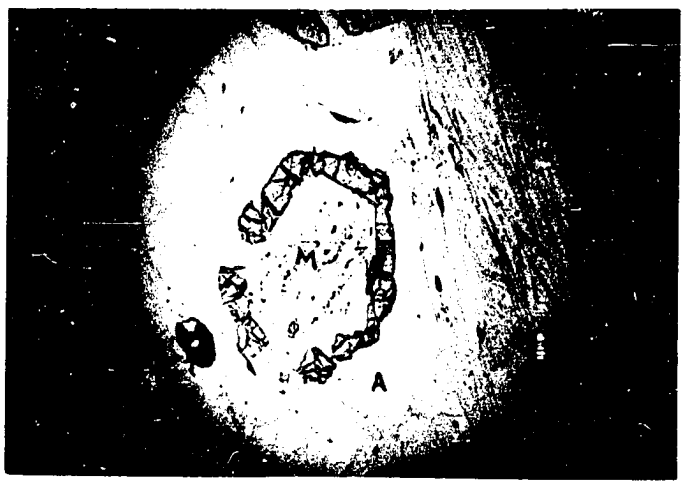
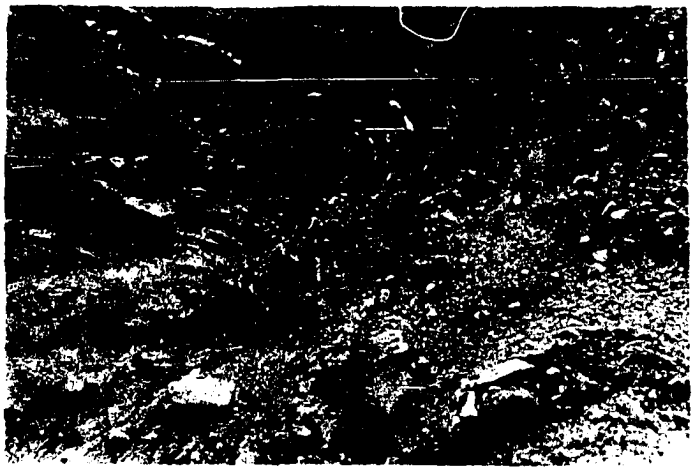
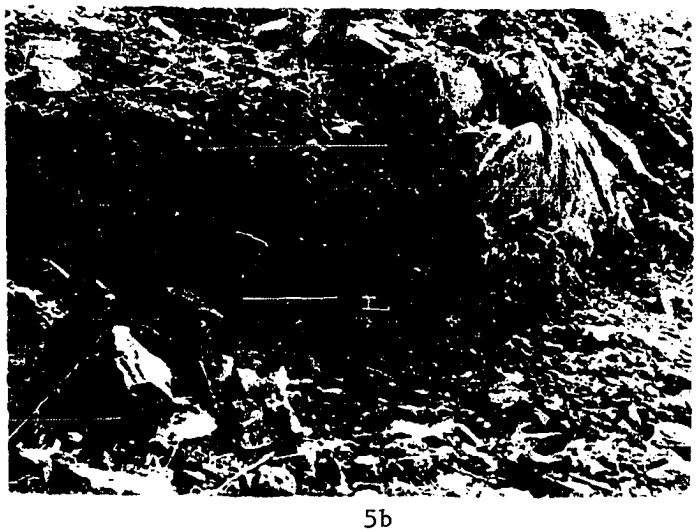


Fig. 4a. Garnet porphyroblast enclosing laths of muscovite, M, in schist F113.

Fig. 4b. Refolded recumbent fold in micaceous quartzite collected in the borrow-pit at 6.1 mile on the Elliot Highway.

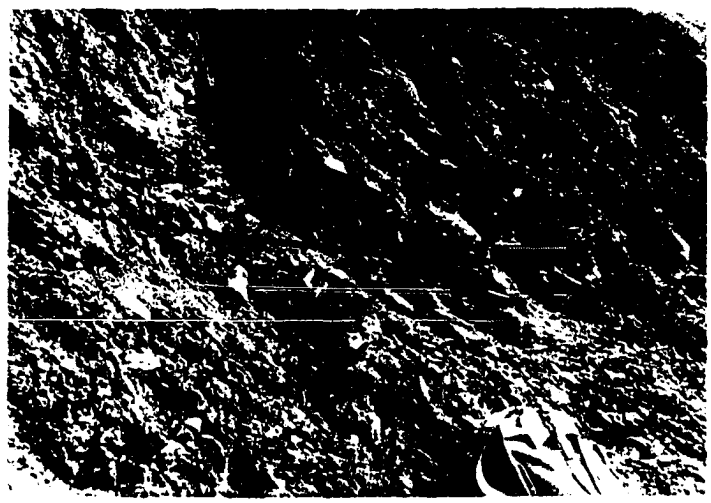


5a



5b

Figs. 5a,5b. Recumbent folds in the 6.1 mile borrow-pit, viewed from the north-west. Note direction of yielding along sheared axis.



6a

6b

Figs. 6a,6b. Recumbent isoclinal folds in the 6.1 mile borrow-pit viewed from the north-northwest.

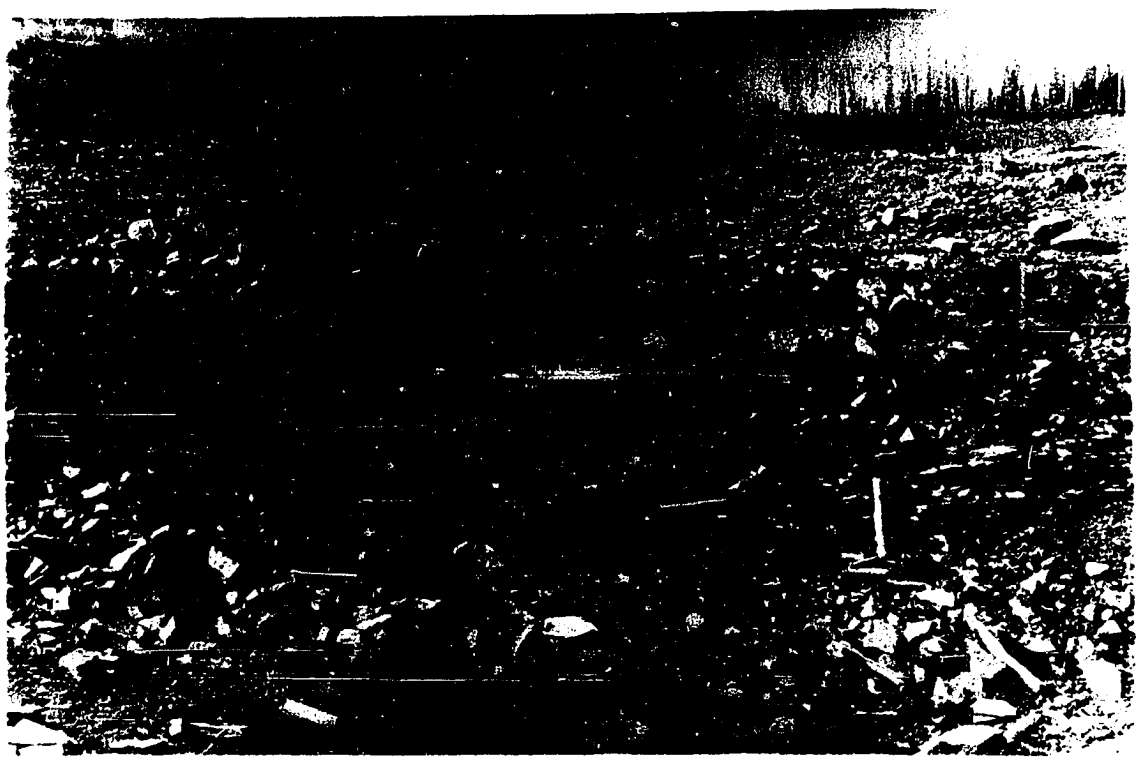


Fig. 7. Recumbent folding in the 6-1 mile borrow-pit viewed from the northeast along the tectonic a axis.

Fig. 8. Recumbent fold in the quartzite exposed in Spruce Creek. (Locality 31, Plate 1.)

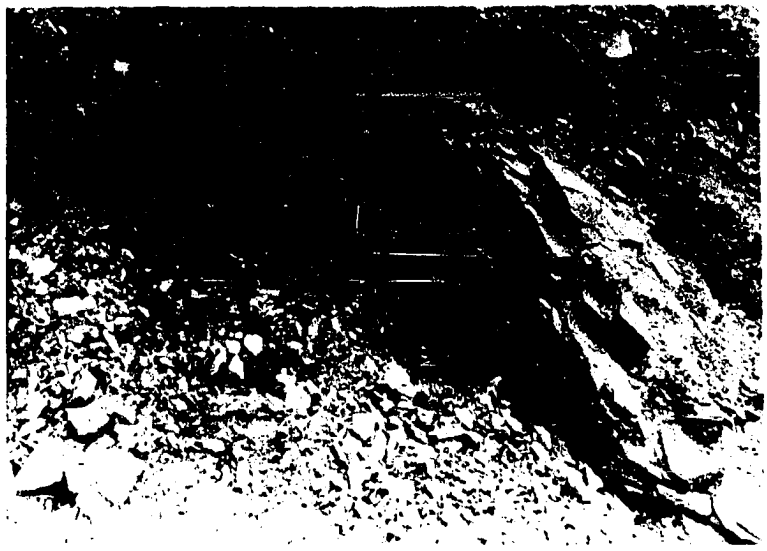


Fig. 9a. Style of folding around northeasterly trending axes, (Locality 19, Plate 1).

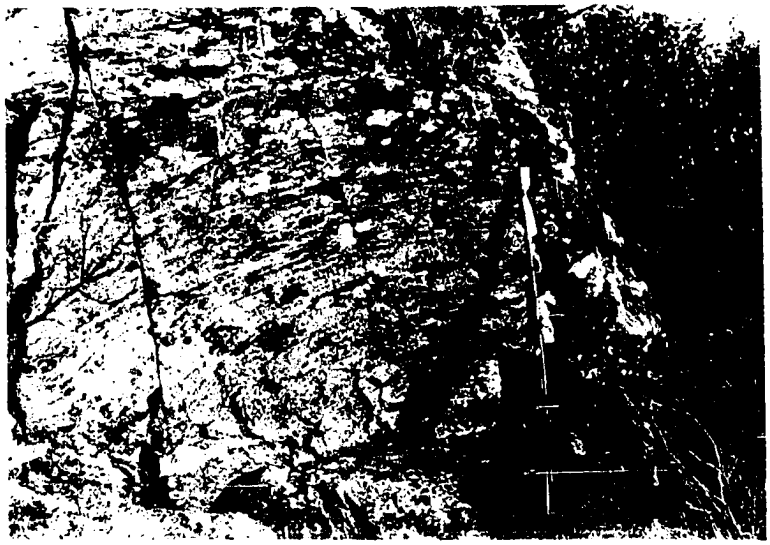


Fig. 9b. Broad warping of quartzites along northwesterly trending axes, (Locality 15, Plate 1).

Figures 5a and 5b document the isoclinal recumbent style of folding in the borrow-pit at 6.1 mile on the Elliot Highway. The direction of yielding and shearing off of the overturned limbs of folds indicates a principle direction of yielding to the southwest.

Figures 6a and 6b illustrate the same fold style, but undulations of the northwesterly trending axes are evident. A section in the c-b plane of one of these folds, viewed along the tectonic a axis, (Fig. 7) shows that this structural style can be deceptive in this view, which gives the appearance of simple folding in bedded rock units. Figure 8 illustrates the fold geometry of a quartzite bed at locality #31 demonstrating the recumbent fold style which is prevalent throughout the eclogite-bearing terrane.

Later folding along northeasterly axes produces folds of varying style, generally with axial planes dipping steeply to the southeast (Fig. 9a). Superposition of these folds upon previously formed isoclinal recumbent structures creates culminations and depressions of the earlier fold axes, such as those illustrated in the borrow-pit.

Culminations and depressions of the northeasterly trending fold axes may indicate a third phase of folding, again along northwesterly trending axes. Figure 9b shows a broad open fold at locality #15 of Plate 1 which may be of this type.

Stereographic plots of the measured fold axes and b mineral lineations from the eclogite-bearing errrane show a strong orthorhombic symmetry, (Fig. 10). This is in contrast to the monoclinic symmetry shown by a stereographic plot of the structural elements in the schists to the south of the inferred discontinuity (Fig. 11). The strong northeasterly fabric element is apparent in both stereograms, but only a suggestion of a northeasterly trend is seen in the chlorite-bearing schists of the Cleary Summit area.

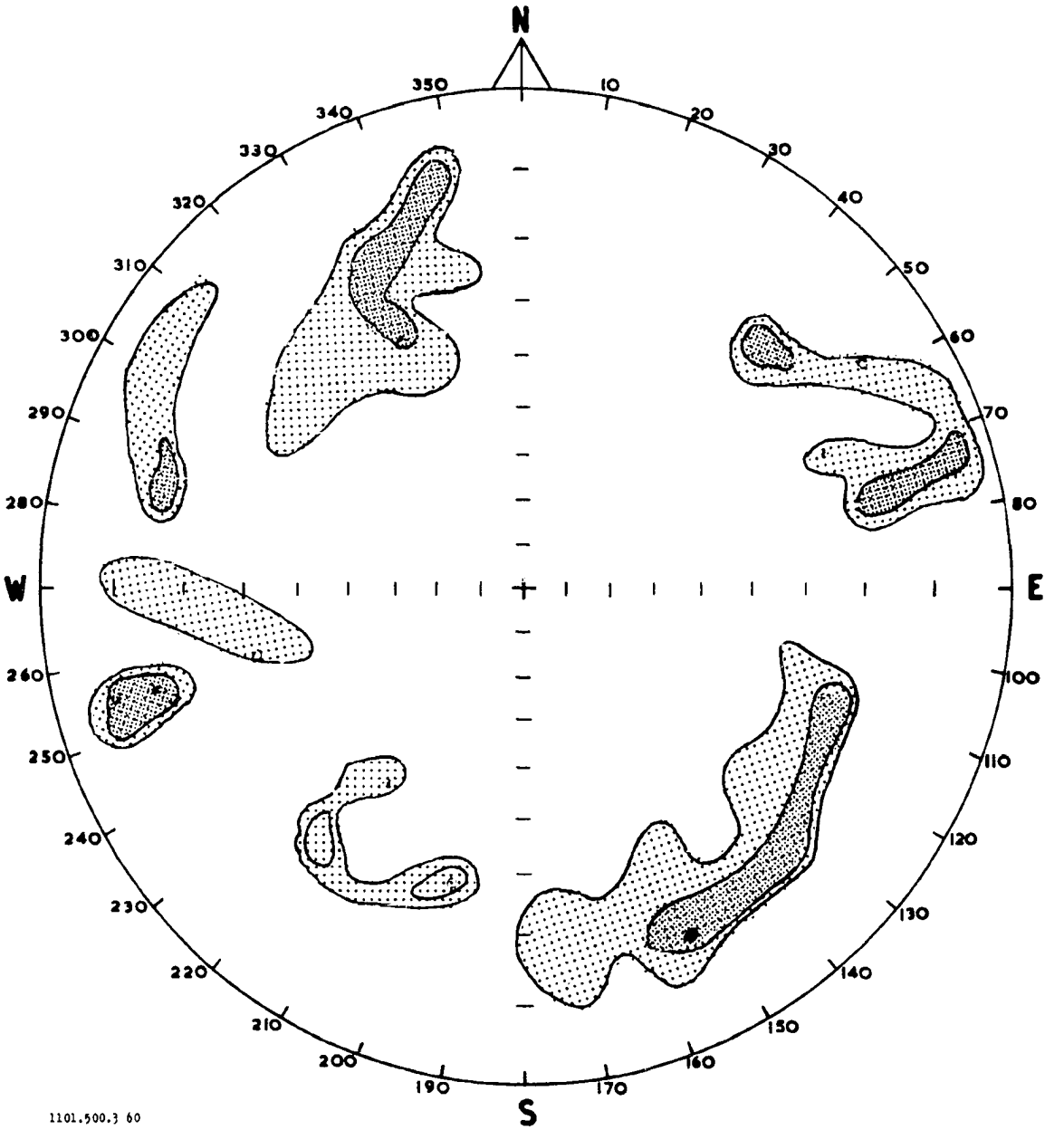


Fig. 10. Lower hemisphere stereographic plots of fold axes and b mineral lineations in the eclogite-bearing terrane. Contours at 4, 6 and 8% intervals for 175 plots.

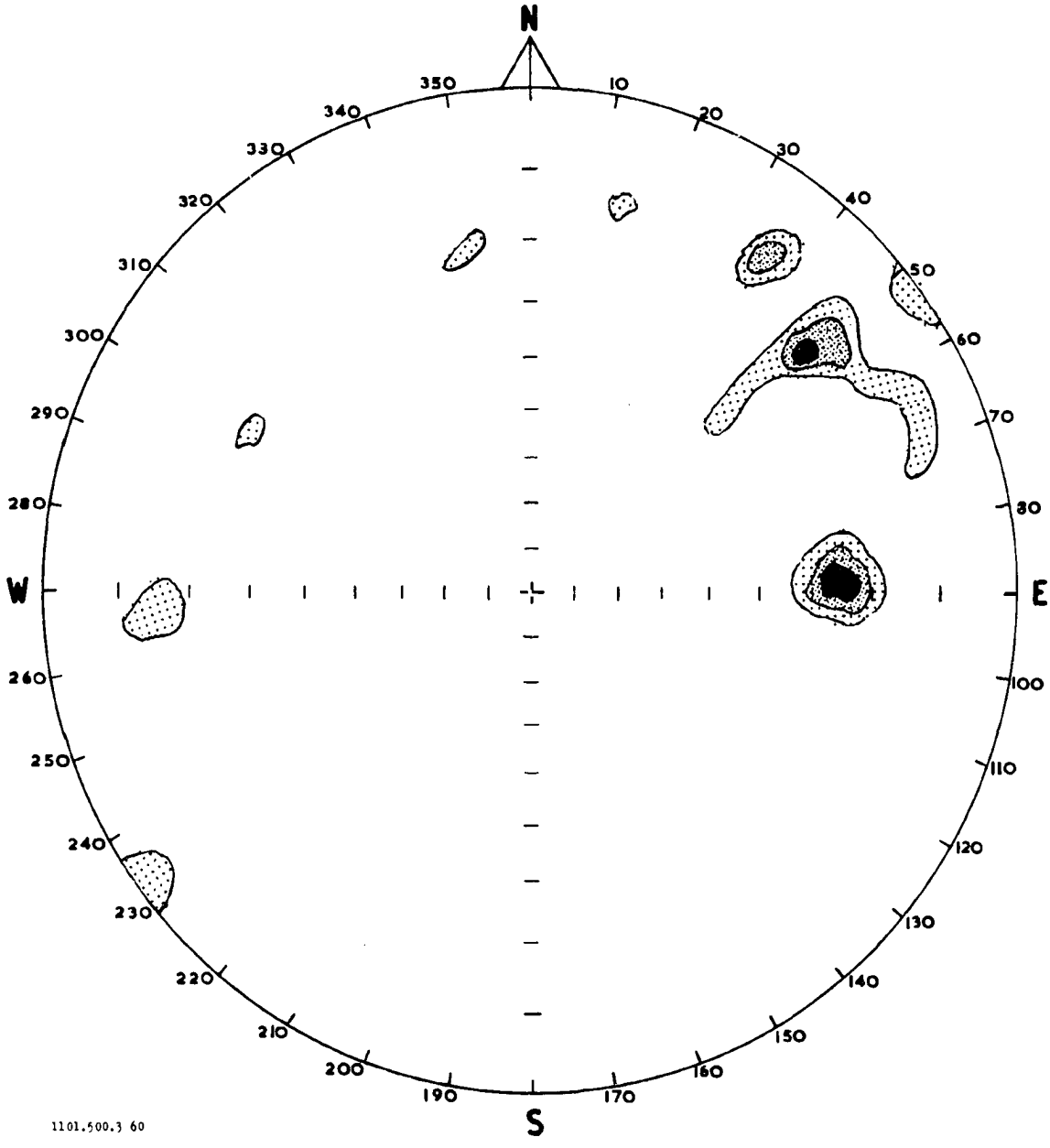


Fig. 11. Lower hemisphere stereographic plots of fold axes and b mineral lineations in the pelitic schists of the Cleary Summit area. Contours at 4, 6 and 8% intervals for 78 plots.

Stereographic plots of the pole to joint-planes, Fig. 12, indicates that vertical jointing is dominant, but that a strong east-west joint set, dipping about seventy degrees to the south is present in the calc-magnesian terrane. Where detected, faulting appears to be parallel to the major joint-planes and concordant with topographic linears.

Structure sections 1-14, Plate 2, are a composite of three sets of sections orientated a few degrees from NNW so as to intersect the maximum number of outcrops. Discrepancies between adjacent sections in Plate 2 appear to correlate with projected traces of observed fault zones. The northeast-southwest structure section is a generalized section based on all available data.

Figure 14 is a block diagram showing the structural style of the eclogite-bearing terrane. The eclogitic rocks were deformed by all of the recognized phases of folding and are essential units within the crystalline schist sequence.

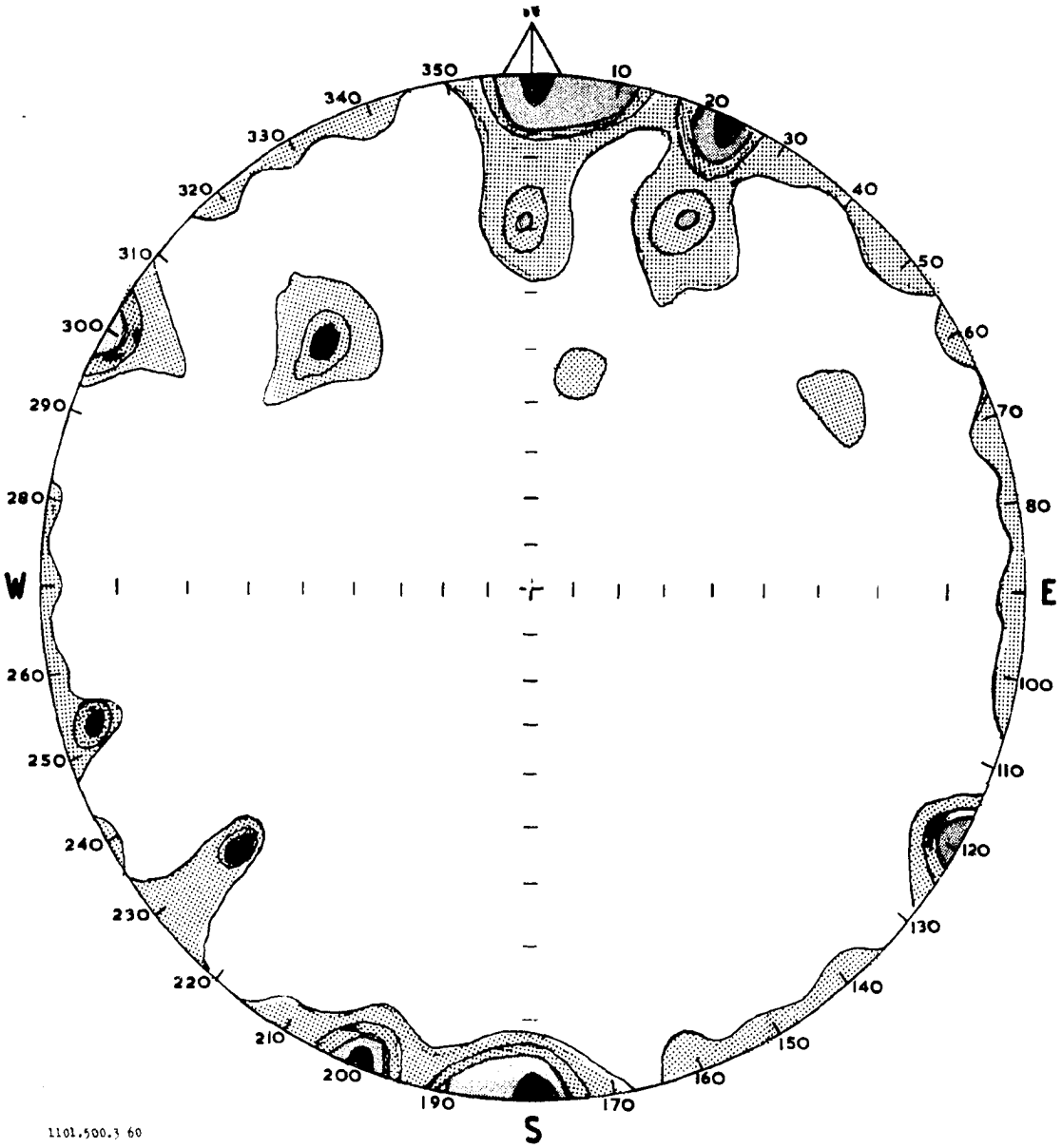


Fig. 12. Lower hemisphere stereographic plots of joint-plane poles in the eclogite-bearing terrane. Contours at 2, 4, 6 and 8% intervals for 196 plots.

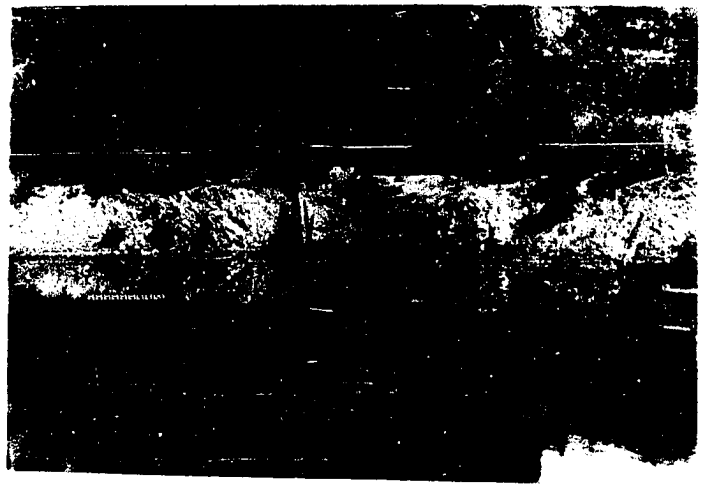


Fig. 13a. Fault zone in the valley of Dome Creek, (Locality 6, Plate 1).

Fig. 13b. Close view of schists on the block north of the fault showing drag to the plane of the fault.

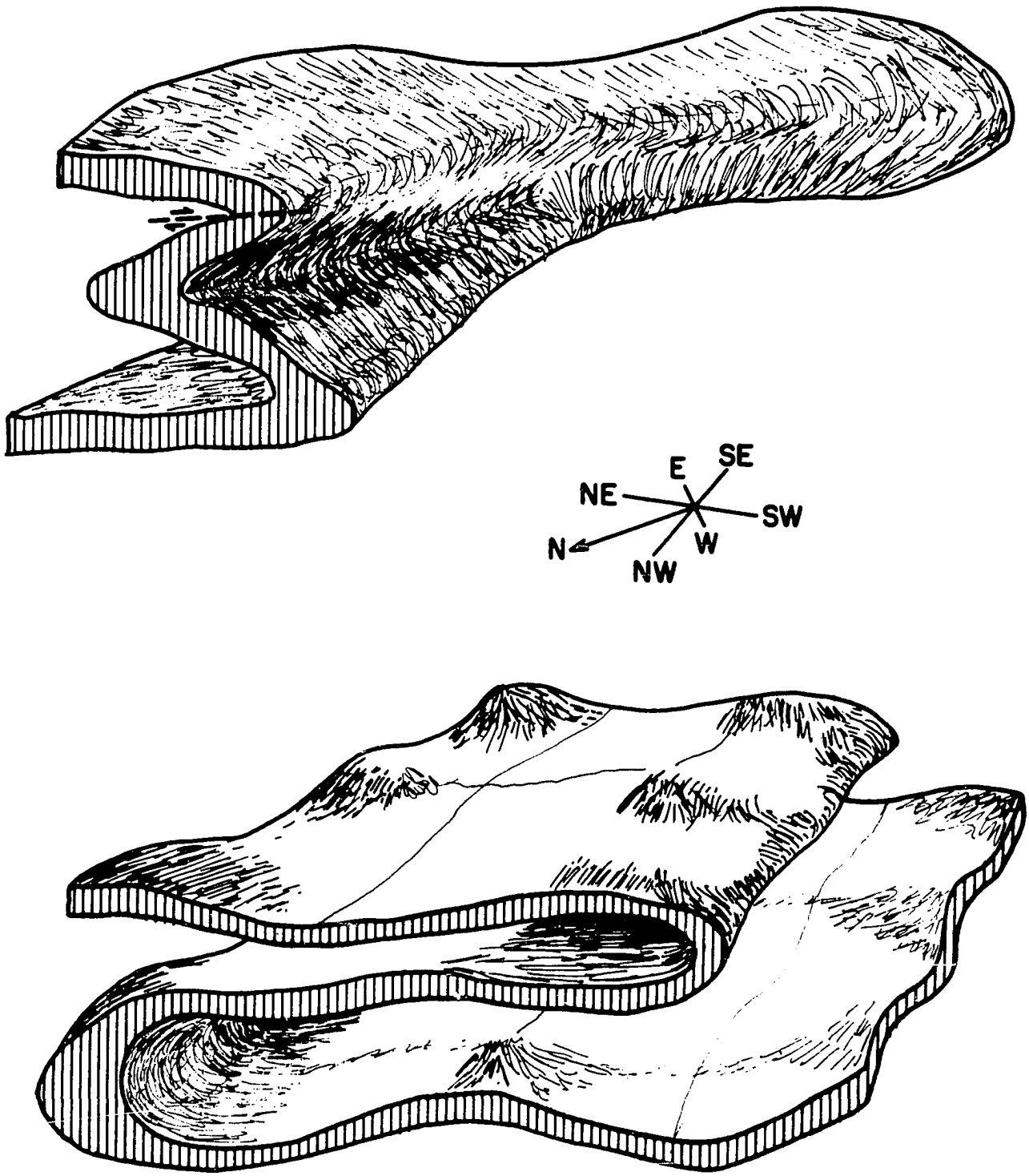


Fig. 14. Diagram illustrating the style of folding in the eclogite-bearing terrane.

PETROLOGY

PETROGRAPHY

Quartz-mica schists

The typical mineralogy is quartz-garnet-muscovite-plagioclase (± biotite, chlorite). Rutile, sphene, apatite and opaques are frequent accessories. The quartz fabric is granoblastic and the untwinned albite is porphyroblastic.

Subhedral muscovite shows a strong preferred orientation, and skeletal garnet porphyroblasts enclose orientated laths of muscovite and biotite, as shown in Fig. 4a. This suggests that the garnet is formed from these minerals.

Biotite is restricted to the rocks south of the calc-magnesian belt and is pleochroic in brown to straw. Pennine chlorite is faintly pleochroic in green and olive-green, and is present in the eclogite-bearing terrane only in obviously retrograded rocks.

Graphitic quartz-mica schists are commonly associated with eclogitic horizons.

The common occurrence of biotite and/or chlorite in the schists to the south of the calc-magnesian belt indicates that they are of upper greenschist facies, while the schists intercalated with the eclogitic rocks appear to be of the lower amphibolite facies.

Pelitic schists

The basic mineralogy is the same as for the quartz-mica schists, with which these rocks form a complete gradation. Most of the pelitic schists are garnetiferous, and the lack of garnet can be ascribed to bulk chemical controls. Figures 15a, b, c show the differing morphology of garnets from

a b

c

Figs. 15a,b,c. Differing morphological habit of garnets in separate laminae of the same garnet-mica schist, (F9).

adjacent laminae in the pelitic schist F9. Peripheral retrograde alteration of garnets is common, and albite and chlorite, (pennine) occur in the stress-shadow areas adjacent to the garnet porphyroblasts.

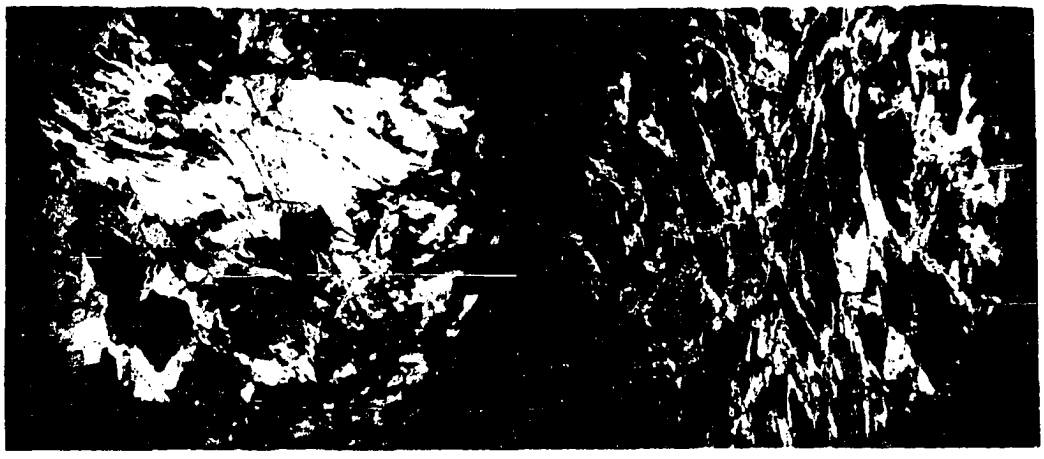
Two generations of muscovite are present; later euhedral laths which define an S_2 plane transecting an earlier foliation, (S_1). Biotite also defines two S-planes. Faintly pleochroic biotite laths are part of the synkinematic fabric, while deeply absorptive biotite rosettes are occasionally observed. These latter are probably due to localized hornfelsing. Chlorite, (pennine), if present occurs in the synkinematic fabric, and it also occurs as a retrograde alteration product of garnet.

Rutile is the predominant titaniferous mineral, though sphene is occasionally observed. Tourmaline, (schorlite) is generally zoned, with euhedral overgrowths on rounded nucleii of apparently detrital tourmaline, see Figure 3a.

Carbonaceous matter is common in some of the pelitic schists associated with the eclogitic rocks, and there is an apparent inverse correlation between the relative abundance of carbonaceous matter and the paucity of garnet.

Biotite and chlorite are more common in the pelitic schists to the south of the eclogite-bearing terrane, suggesting that the metamorphic grade of these schists is less than that of those in the calc-magnesian terrane. The lack of chlorite and biotite and the greater abundance of garnet in the eclogite bearing terrane suggests that chlorite and biotite, possibly with muscovite were reactants in the production of the garnets in the pelitic schists.

Special emphasis was placed on the collection of highly aluminous pelitic schists, and they failed to show any Al_2SiO_5 polymorph in any of the variants which were studied. No gneissic rocks were observed in the eclogite-bearing terrane.



a b

c

Figs. 16a,b,c. Typical synkinematic fabrics in the eclogitic rocks.

a) Garnet-omphacite-phengite, (F50).

b) Omphacite-clinozoisite, (F75).

c) Garnet-calcite-phengite, (F78).

Estimated modes of the quartz-mica schists and the pelitic schists are given in Appendix 1.

Calc-magnesian rocks

Three varieties of calc-magnesian rocks have been collected which correspond to the types a, b and c described by Prindle, (1913).

1. Garnet-clinopyroxene (± calcite, quartz, plagioclase, "epidote").
2. Garnet-clinopyroxene-amphibole (± calcite, quartz, plagioclase, "epidote").
3. Garnet-amphibole (± calcite, quartz, plagioclase, "epidote").

Muscovite or phengite may achieve major proportions in some variants and apatite, sphene and opaques are frequent accessories. Biotite, chlorite and rutile are common in group 3.

1) Garnet-clinopyroxene (± calcite, quartz, plagioclase, "epidote") rocks. Textures vary from mylonitic, banded and/or laminated varieties, to dense, compact rocks. Pale pink garnets are small and poikiloblastic, and they often display a more homogeneous marginal zone. Copious inclusions of clinozoisite, calcite and quartz suggest that the garnets were formed by the reaction of these minerals. Peripheral alteration of garnet to a blue-green amphibole is common, but not quantitatively important, (Fig. 17a).

Fresh pale green omphacitic pyroxene greatly predominates over highly altered dark green diopsidic pyroxene which is also present in some rocks.

Untwinned albite is present only in the mylonitic variants and is usually associated with garnet and chlorite. Quartz generally occurs as granoblastic aggregates and twinned calcite is found as an essential component of the synkinematic fabric as well as in discordant veinlets.

No reaction relations were observed between calcite and quartz; a fact of importance to the petrogenesis of these rocks.

Fig. 17a. Marginal alteration of garnet to hornblende, (F39).

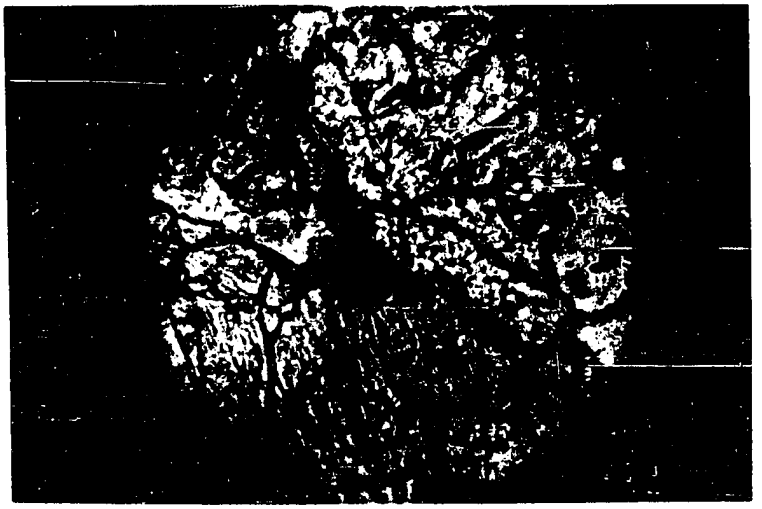


Fig. 17b. Marginal alteration of calcic-glaucophane to hornblende, (F50).

Pseudormorphs of epidote and quartz after garnet are occasionally present, but clinozoisite is much more abundant, and it often attains major proportions in selected compositional layers.

Sphene is the dominant titaniferous phase, and apatite, orthite and opaques are common accessories.

2) Garnet-pyroxene-amphibole (± calcite, quartz, plagioclase, "epidote") rocks

Textural variations are more limited than those described in the preceding group, and dense or finely laminated varieties predominate.

Pale pink helictitic garnets are characterized by euhedral overgrowths on subhedral poikiloblastic cores. Inclusions include clinozoisite, quart and calcite.

The clinopyroxene is green and generally poikiloblastic, amphibole is pale green with little absorption, and alters to a dark green highly pleochroic hornblende proximal to garnet, (Fig. 17b).

Albite, is more abundant than in the amphibole-free variants of the previous group, and tends to occur in the stress shadow of the garnets and clinopyroxenes.

Muscovite is common and is present in the synkinematic fabric and also as laths in transecting shear planes.

Calcite is more abundant than quartz, but again no reaction between the two is seen where they coexist. Discordant veinlets of both minerals are seen.

Clinozoisite is the most common of the epidote-group minerals, but zoisite is frequently present in the more siliceous rocks. Both minerals are common inclusions in the garnets.

Apatite forms aggregates, and sphene, sometimes armouring rutile cores, (Fig. 18a), generally occurs as granule trains.

Tourmaline, orthite and graphite are minor accessories.

3) Garnet-amphibole (± calcite, quartz, plagioclase, "epidote") rocks

Textures vary from rather dense and massive to almost schistose varieties. Garnet porphyroblasts are large, up to 8 mm, and euhedral overgrowths on subhedral poikiloblastic cores are prevalent. Helictitic garnets are rare, and most have kelyphitic margins.

Synkinematic subhedral amphibole (X=pale green, Y=green, Z= deep green) is the most ubiquitous amphibole, but some rocks have instead an amphibole with a distinctive pleochroic scheme, (X=colourless, Y=green, Z=green-blue). Alteration of both varieties close to garnet forms a dark green hornblendic amphibole.

Quartz and calcite are present both in the synkinematic fabric and as veinlets. No reaction between the two is observed.

Untwinned albite grains are common, and complex porphyroblasts are present in several rocks.

Muscovite and biotite laths are primary synkinematic phases in many rocks but late muscovite defines an S_2-plane while secondary biotite tends to have an hornfelsic texture.

Clinozoisite is the main epidote-group mineral, and it is frequently the dominant mineral in selected compositional layers.

Sphene, rutile apatite and opaques are accessories. Rutile is the dominant titaniferous phase, but in one rock, (F167), discordant veins of sphene were observed, see Figure 18b.

Fig. 18a. Sphene overgrowths on rutile cores, (F99).

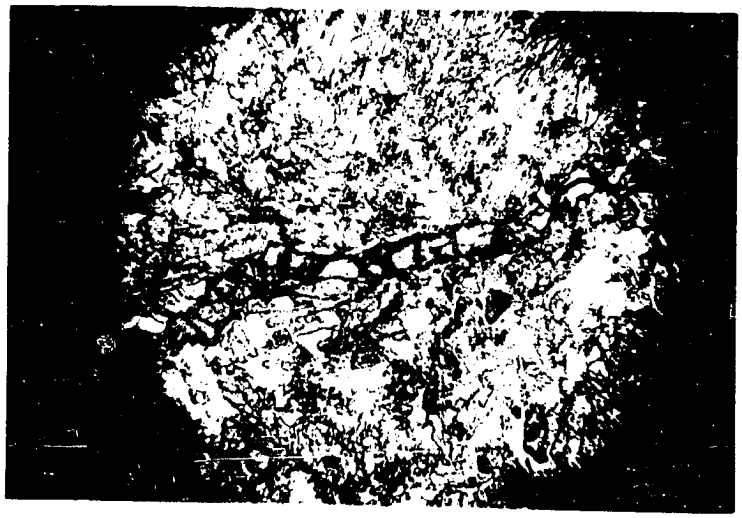


Fig. 18b. Discordant vein filled with sphene, (F167).

Carbonaceous material is very common in this group of rocks, although it is not modally important. The pelitic rocks seem to be above the garnet isograd based on petrographic evidence; south of the discontinuity bounding the eclogite-bearing terrane, the schists are of the uppermost greenschist facies, and within the eclogitic terrane mineral assemblages appear to be in the amphibolite facies.

BULK CHEMICAL COMPOSITION

Selection of the rocks for chemical analysis was based on representative mineralogy, minimal alteration and the ease of separation of the constituent minerals. Possible variations in the physical conditions of metamorphism due to wide geographic distribution were minimized by collecting most of the rocks from the small borrow-pit located at 6.1 mile on the Elliot Highway. In order to obtain representative assemblages from all of the important rock-types, however, it was necessary to select two garnet-mica schists (F10 and F11) and one amphibolite, (F162) from other localities. Bulk chemical, modal and C.I.P.W. normative analyses are presented in tables 2a, 2b and 2c.

Comparison of the normative and modal analyses of these rocks shows that undersaturation, as expressed by normative nepheline, olivine and calcite is reflected only by calcite in the mode. This suggests that the physical conditions of metamorphism are not compatible with the formation of olivine. No modal hypersthene was seen in any of the rocks, though normative hypersthene occurs in the norms of the more siliceous variants.

Normative anorthite is present in all of the eclogitic rocks, and though no calcic plagioclase was seen in any of the rocks, epidote-group minerals, (mainly clinozoisite) occur in many rocks.

Table 2a. Whole rock chemical analyses

	PELITIC SCHISTS				AMPHIBOLITES				(ECLOGITIC ROCKS)						
OXIDE	Oz-Ab-Musc-Chlor		Gt-Qz-Musc-Ab		Am	Gt-Am-Ct-Qz			Gt-Px-Am-Ct-Qz			Gt-Px-Ct-Qz			
	F10	F11	F29	F71	F229†	F230†	F136	F162	F50	F86	F89	F39	F101	F201	F231†
SiO_2	55.03	60.64	53.87	62.79	51.06	41.99	42.95	47.21	35.22	68.26	38.09	28.61	30.02	54.61	37.72
TiO_2	0.75	1.39	3.96	1.26	1.19	3.03	1.31	0.73	2.71	0.88	2.32	2.63	2.45	1.69	2.06
Al_2O_3	24.51	15.81	17.49	15.48	14.54	20.46	14.52	12.01	9.34	10.01	6.46	9.71	8.58	12.92	10.95
Fe_2O_3	4.77	1.90	3.80	1.80	2.58	2.49	2.34	2.47	3.14	4.06	5.07	3.58	3.41	3.91	5.25
FeO	1.24	7.42	1.16	4.97	8.81	14.01	6.90	8.58	5.89	5.41	5.85	10.15	10.11	4.97	5.65
MnO	0.03	0.09	0.02	0.11	0.15	0.14	0.14	0.32	0.13	0.17	0.44	0.42	0.66	0.14	0.18
MgO	1.50	4.02	3.38	2.56	6.15	5.38	7.49	13.68	9.66	3.66	7.39	6.80	4.63	6.51	8.71
CaO	0.13	1.56	3.20	1.77	9.69	5.92	10.85	10.57	19.73	5.43	23.22	22.32	24.00	11.79	19.92
Na_2O	0.79	1.32	1.78	1.56	3.84	3.23	1.53	1.49	0.63	1.63	1.59	1.52	2.22	1.51	1.50
K_2O	6.37	2.87	4.03	4.42	0.43	1.08	3.17	0.20	1.39	0.13	0.04	0.09	0.07	0.24	0.29
P_2O_5	0.07	0.09	0.32	0.09	0.12	0.07	0.17	0.18	0.25	0.04	2.09	3.09	2.02	0.21	0.47
H_2O^+	5.01	2.47	6.17	2.91	1.56	2.11	1.84	2.70	6.64	0.59	1.04	7.03	3.24	1.73	0.86
H_2O^-	0.13	0.15	0.10	0.05	0.18	0.11	0.10	0.13	0.05	0.05	0.00	0.05	0.10	0.00	0.14
Cr_2O_3	0.0072	0.012	0.054	0.0052	n.d	n.d	0.042	0.046	0.023	0.018	0.0039	0.0031	0.0091	0.072	n.d
NiO	0.0036	0.0066	0.0026	0.0028	n.d	n.d	0.0018	0.0072	0.0008	0.0049	0.0005	0.0058	0.0029	0.0075	n.d
CO_2	n.d	n.d	n.d	n.d	n.d	n.d	6.62	n.d	5.42	0.08	6.22	4.16	8.24	n.d	6.1
Total	100.34	99.75	99.84	99.78	100.30	100.02	99.97	100.36	100.22	100.42	99.92	100.17	99.76	100.31	99.80
S.G.	2.826	2.808	2.892	3.100	3.033	3.158	n.d	n.d	3.163	3.003	3.010	3.420	3.355	3.255	n.d

† Analysis: H. Matsumoto & H. Haramura

All other analyses: H. Haramura and T. Katsura

Table 2b. Whole rock norms

Normative	Pelitic Schists				Amphibolites				Rocks			Eclogitic		
Mineral	Qz-Ab-Musc-Chlor		Gt-Qz-Musc-Ab		Am.	Gt-Am-Ct-Qz			Gt-Am-Px-Ct-Oz			Gt-Px-Ct-Qz		
	F10	F11	F29	F71	F229	F230	F136	F162	F50	F86	F89	F39	F101	F201
Quartz	23.45	27.82	17.23	26.29	-	-	11.07	-	-	39.15	0.08	-	-	14.76
Orthoclase	40.14	17.95	25.90	27.63	2.58	6.61	17.10	1.20	8.20	0.80	0.24	0.54	0.42	1.47
Albite	7.57	12.55	17.38	14.82	35.06	25.89	12.55	13.59	5.65	15.33	14.61	10.64	8.93	14.06
Anorthite	0.20	7.57	14.99	8.67	21.52	29.97	7.73	25.90	18.54	20.54	10.61	19.85	13.49	28.80
Nepheline	-	-	-	-	-	2.50	-	-	-	-	-	1.99	6.83	-
Leucite	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Corundum	18.92	9.14	6.71	5.92	-	3.82	5.45	-	-	-	-	-	-	-
Diopside	-	-	-	-	21.25	-	-	-	-	-	-	-	-	-
Hypersthene	4.42	20.61	10.15	12.62	7.82	-	25.66	19.76	20.09	12.42	2.14	-	-	9.35
Olivine	-	-	-	-	7.06	23.96	-	14.50	3.09	-	-	17.87	9.18	-
Magnetite	1.48	2.11	-	1.99	2.74	2.69	2.27	2.68	3.30	4.47	5.42	3.83	3.63	4.32
Ilmenite	1.11	2.05	1.99	1.86	1.68	4.37	1.67	1.03	3.77	1.28	3.31	3.75	3.48	2.44
Apatite	0.16	0.20	0.73	0.20	0.25	0.15	0.32	0.38	0.52	0.09	4.47	6.61	4.30	0.46
Calcite	-	-	-	-	-	-	16.17	-	25.26	-	15.53	23.27	25.77	-
Hematite	2.56	-	2.92	-	-	-	-	-	-	-	-	-	-	-
Rutile	-	-	2.01	-	-	-	-	-	-	-	-	-	-	-

Table 2c. Modes of analyzed rocks.

ROCK NUMBER	CLINO-PYROXENE	AMPHIBOLE	GARNET	CALCITE	QUARTZ	PLAGIOCLASE	MUSCOVITE	BIOTITE	CHLORITE	EPIDOTE	APATITE	SPHENE	RUTILE	OPAQUES	TOURMALINE	PHLOGOPITE	"TALC"	ORTHITE	"GRAPHITE"	COLLOPHANE
F10	----	----	0.8	----	36.1	6.2	40.2	4.0	5.8	----	---	---	---	4.7	1.6	---	---	---	0.6	---
F11	----	----	2.8	----	34.8	5.6	13.3	11.3	23.3	----	0.2	5.3	---	0.7	1.8	---	---	---	0.3	---
F29	----	----	----	----	16.2	10.6	41.6	----	---	----	---	9.4	6.2	5.1	---	---	5.6	1.4	---	2.1
F70	----	2.6	24.3	----	32.6	----	----	----	---	10.2	0.1	---	6.4	1.2	1.2	---	20.3	---	---	---
F71	----	----	13.2	----	22.4	5.7	49.9	2.7	---	2.1	0.3	---	1.8	0.2	0.3	---	1.2	---	0.4	---
F136	----	30.4	12.1	15.3	---	3.2	9.3	18.4	---	---	2.2	---	4.8	2.0	0.9	---	1.5	---	0.7	---
F162	----	55.8	7.6	----	---	6.1	7.1	0.2	7.5	2.8	2.6	---	7.5	0.3	---	---	1.2	---	---	---
F50	16.8	21.5	14.3	28.1	2.1	---	5.5	----	----	3.9	0.5	5.4	---	0.8	---	0.7	1.0	---	---	---
F86	13.2	11.2	18.2	---	34.7	1.7	---	----	----	2.7	0.7	---	3.8	0.8	---	2.1	8.6	1.1	0.5	---
F89	16.3	28.4	23.1	13.4	----	----	---	----	----	1.1	10.8	5.8	---	1.0	---	---	----	---	---	---
F93	12.3	16.8	25.9	26.5	----	----	---	----	----	----	6.2	7.1	---	3.0	---	1.1	----	0.4	---	---
F99	5.4	13.3	17.3	----	25.9	15.2	0.3	----	----	18.8	----	0.2	1.1	---	0.3	1.4	----	---	---	---
F39	30.3	4.2	18.8	29.0	---	---	0.3	----	----	0.3	6.4	5.4	---	1.1	---	2.6	----	1.0	---	---
F75	44.3	7.9	8.6	19.4	---	1.9	---	----	----	8.2	0.7	5.2	---	1.5	---	0.9	---	0.7	0.8	---
F78	25.7	5.7	11.2	48.7	---	---	---	----	----	---	1.8	2.7	---	3.2	---	---	---	0.9	---	---
F80	46.8	4.0	14.6	12.3	1.8	2.1	---	----	----	3.0	2.1	8.1	---	1.5	---	---	6.7	---	---	0.4
F92	24.5	7.9	28.3	29.1	----	---	---	----	----	0.8	3.9	8.7	---	1.5	---	1.7	---	0.9	0.7	---
F100	31.1	8.9	23.2	12.1	----	---	5.2	----	----	0.8	4.6	7.7	---	3.8	---	1.3	0.9	---	0.4	---
F101	39.2	9.2	21.2	16.2	1.2	---	----	----	----	1.0	5.6	3.9	---	1.9	---	---	2.3	0.8	1.2	---
F201	21.7	8.4	7.3	----	31.1	6.7	----	----	----	4.3	----	5.9	0.9	0.8	---	---	8.2	---	---	---

A wide compositional field is shown by the plots of the analyzed eclogitic rocks on the FMA diagram shown as Fig. 19 when compared with the compositional field defined by the plots of selected eclogite analyses from the literature. The high MgO: FeO ratio displaces the calc-eclogites from the Skaergaard trend, and the alkali-olivine trend is completely dissimilar. Likewise no comparison can be drawn between the eclogites of the Fairbanks district and the compositional trend for basic igneous rocks in terms of the CNK diagram, Digure 20.

The $\left[(Al_2O_3 + Fe_2O_3) - (Na_2O + K_2O)\right]$ -CaO - (FeO + MgO + MnO) diagrams, Figures 21 and 22 are adapted after Winkler, (1963). In Figure 21 the rocks of the Fairbanks area are compared with selected igneous rocks, and with the compositional field defined by analyzed eclogites reported in the literature.

Most of the eclogites from this study fall outside the compositional field of typical eclogites, indicating that these layered, carbonate-bearing eclogites represent a newly recognized compositional variant among the eclogitic rocks. Furthermore many of the calc-eclogites have chemical compositions which are not compatible with basaltic or basic igneous rocks. No igneous analogue could be found for the carbonate-bearing eclogites in an extensive literature search, supporting the conclusions of Forbes, (1965).

The carbonate-free eclogites and garnet-amphibolites of the Fairbanks District are distinguished from rocks of basaltic composition by the low $Na_2O:K_2O$ ratio, (F136) or by the high SiO_2 content.

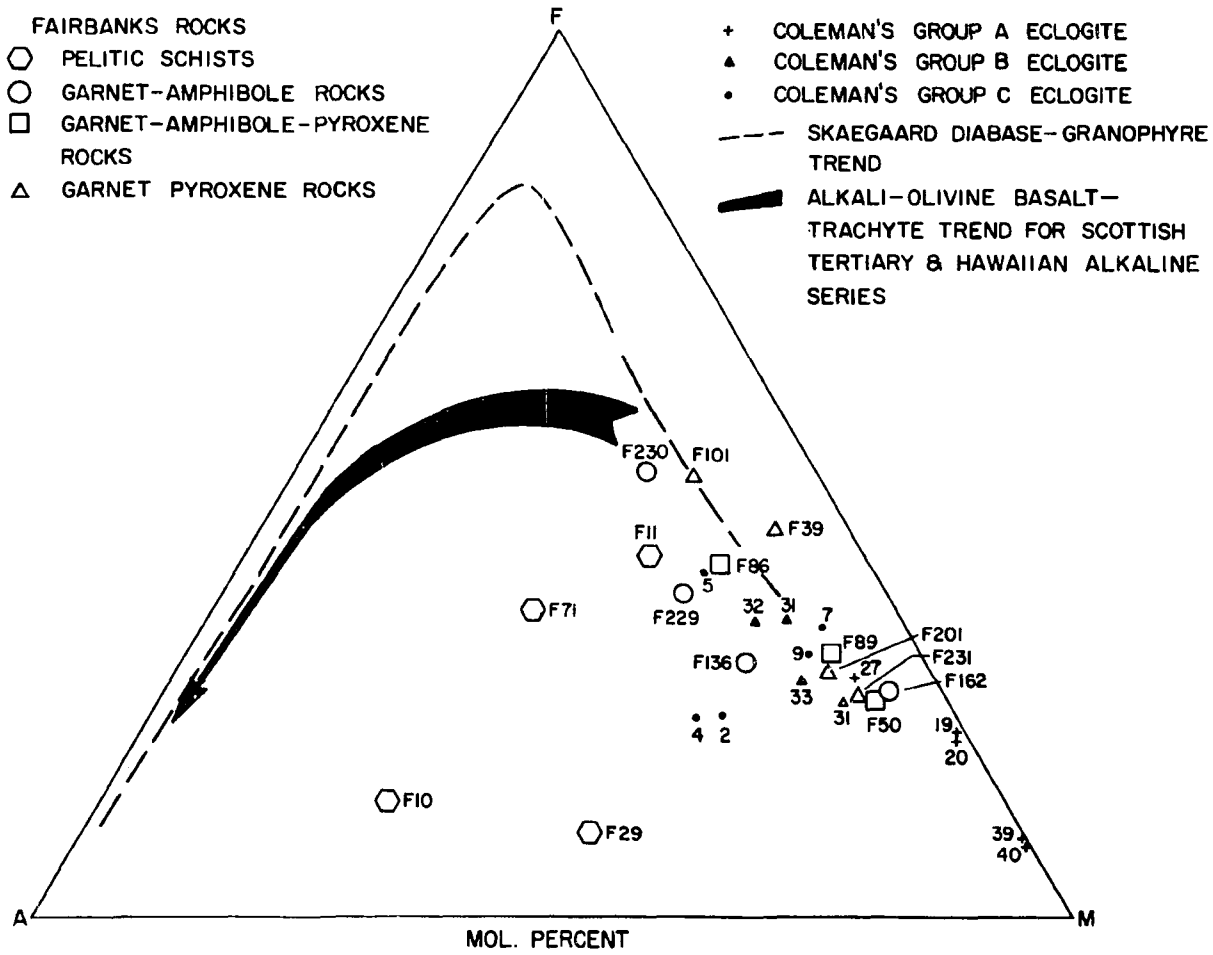


Fig. 19. FMA diagram comparing pelitic schists and eclogitic rocks of this paper with other analyzed eclogites and with basic igneous rocks.

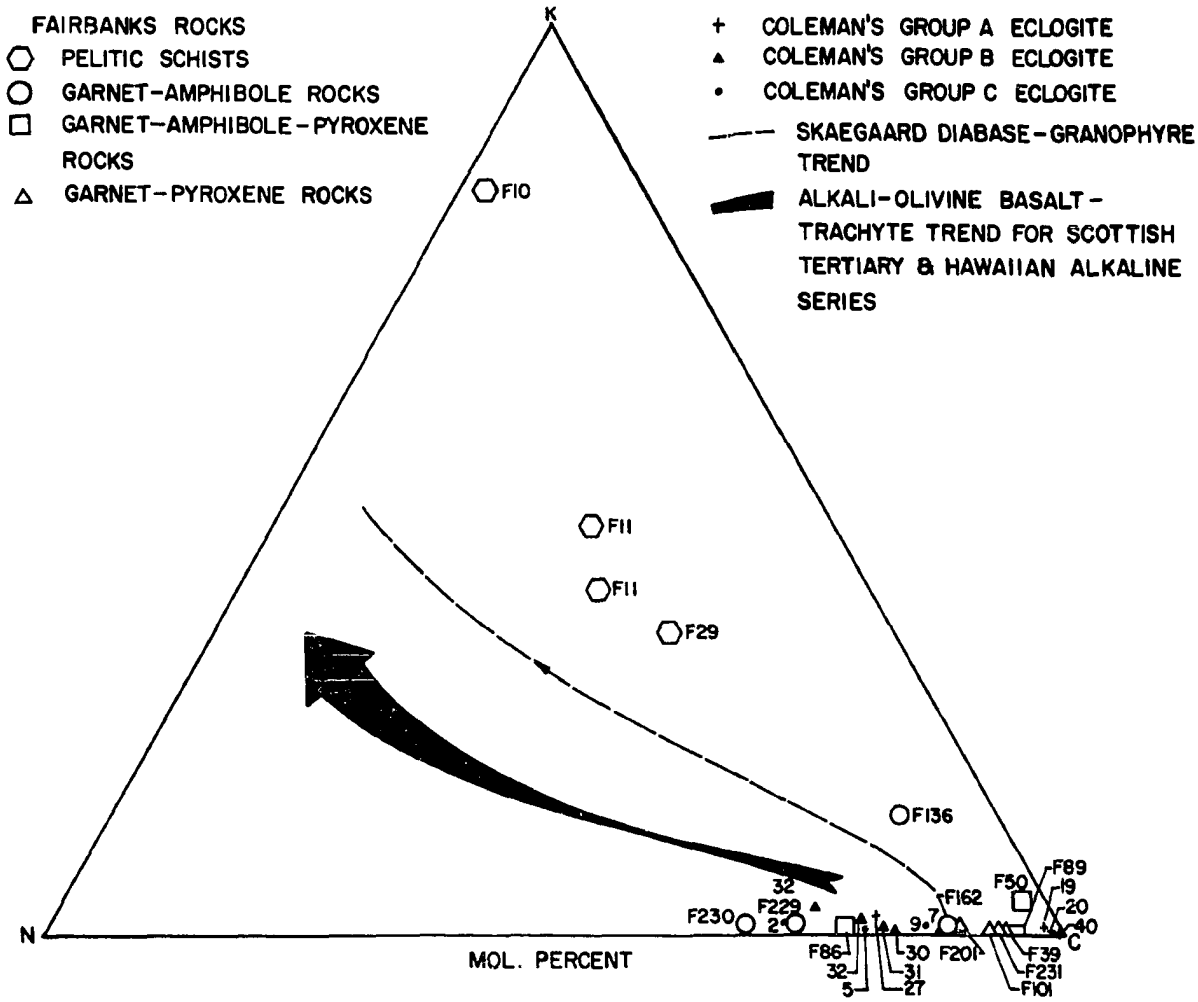


Fig. 20. CNK diagram comparing pelitic schists and eclogitic rocks of this paper with other analyzed eclogites and with basic igneous rocks.

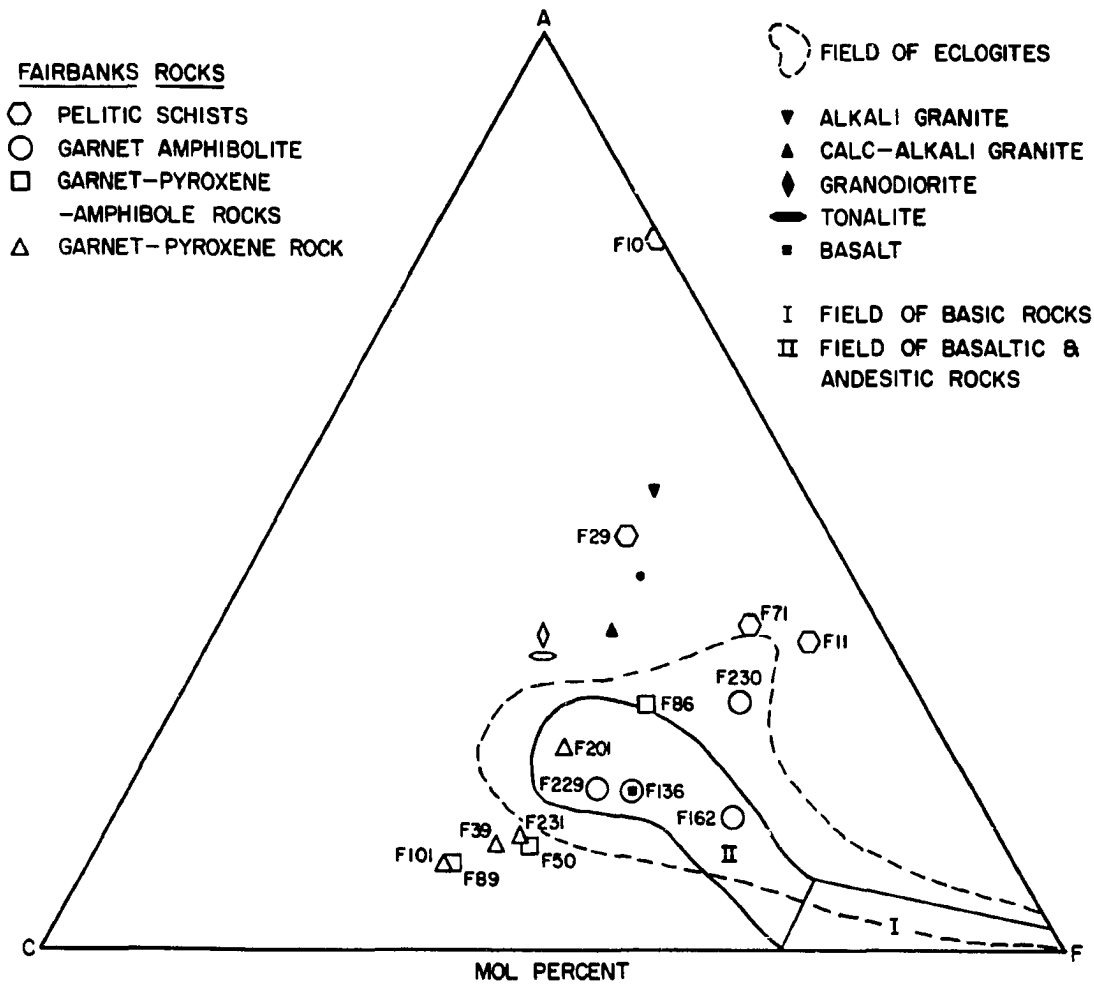


Fig. 21. ACF diagram comparing chemical composition of pelitic schists and eclogitic rocks of the Fairbanks area with other analyzed eclogites and with the compositional field of mafic and ultramafic rocks, (after Winkler, 1963).

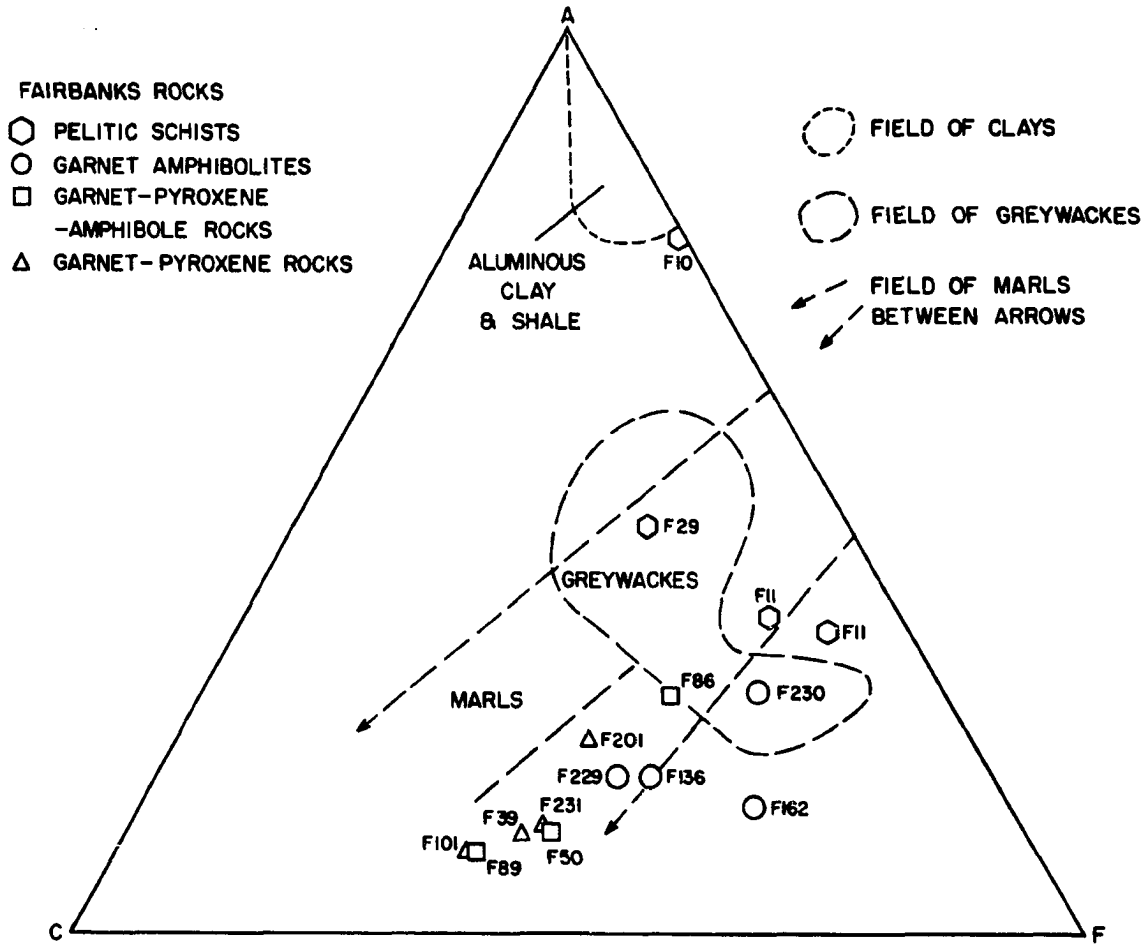


Fig. 22. ACF diagram showing the comparative chemical composition of the analyzed eclogites, amphibolites and pelitic schists from the eclogite-bearing terrane with the compositional fields of sedimentary rocks, (after Winkler, 1963).

Most of the schists are highly aluminous, but schist F29 approximates the composition of an alkali granite in terms of the ACF diagram, Figure 21. This compositional similarity has important petrogenetic implications.

The analyzed rocks are compared in the ACF diagram Figure 22 with a selection of typical sediments. It is evident that the carbonate-bearing eclogites are compositionally analogous to marls, and that the less calcareous variants are comparable to sub-greywackes. Chemical analyses of such sediments are rare, and the most similar analysis to the calc-eclogites which was found in the literature is that of a red mud of terrigenous origin, which was apparently deposited in a near-shore environment, (Clarke, 1924, p. 517).

Hahn-Weinheimer, (1960), Smulikowski, (1964, 1966), and Morgan, (1967) have previously reported eclogites of probable sedimentary origin. The chemical similarity of the carbonate-bearing eclogites of the Fairbanks area with known sediments, and the concordant position of the eclogitic rocks in the sequence leads to the conclusion that all of the calcareous variants are of metasedimentary origin.

CHEMICAL MINERALOGY

One garnet-clinopyroxene-amphibole-phengite quadruplet, two garnet-clinopyroxene-amphibole triplets, ten garnet-clinopyroxene pairs, one garnet-amphibole pair and two garnets from pelitic schists were separated for chemical analysis. Table 1 indicates the parent rocks for these coexistent phases. Chemical analyses, together with selected chemical analyses from the recent literature, were recast into the various petrological parameters by means of a computer program. Appendix 2 identifies the sources of the comparative chemical data used in this study.

Table 1. Key to analyzed rocks and minerals.

Rock No.	Essential Minerals	Whole Rock Analyses	Analysed Minerals Gt	Px	Am	Musc	Biot	K^{40}/Ar^{40} Age Determinations	Oxygen Isotope Analyses
F229	Am-Ct	x						x Am	
F2	Gt-Px-Am-Ct								
F10	Qz - Musc-Ab	x							x
F11	Qz - Musc-Ab Chlor	x							
F25	Gt-Px-Ct								x
F29	Qz - Musc-Ab	x							
F39	Gt-Px-Ct	x	x	x					
F49	Gt-Px-Am-Ct							x Am	
F50	Gt-Px-Am-Ct	x	x	x	x	x			x
F61	Gt-Am-Ct								x
F70	Gt-Qz - Musc		x						
F71	Gt-Qz - Ab -Musc	x	x					x Musc	
F75	Gt-Px-Am-Ct		x	x					
F78	Gt-Px-Am-Ct		x	x					
F80	Gt-Px-Am-Ct		x	x					
F86	Gt-Px-Am-Qz	x	x	x	x				
F89	Gt-Px-Am-Ct	x	x	x	x				x
F92	Gt-Px-Am-Ct		x	x					
F93	Gt-Px-Am-Ct		x	x					
F99	Gt-Px-Am-Qz		x	x					
F100	Gt-Px-Am-Ct		x	x					
F101	Gt-Px-Am-Ct	x	x	x				Am	
F136	Gt-Am-Ct	x	x		x		x	x Musc	
F162	Gt-Am	x						Biot	
F201	Gt-Px-Am-Qz	x	x	x					

Garnet

Eight garnets from garnet-clinopyroxene- (± calcite, quartz,) rocks, five from garnet-clinopyroxene-amphibole- (± calcite, quartz) rocks, one from a garnet-amphibolite and two from pelitic schists were chemically analyzed. These analyses, recast on the basis of 24 oxygen atoms per formula unit are presented in Tables 3a and 3b.

The pyrope content of the garnets from the Fairbanks eclogites varies from 4 to 11 molecular percent, and the ugrandite component from 30 to 51 molecular percent. This small range in molecular end-member composition is surprising considering the wide compositional range of the parent rocks. There is a general agreement between the ugrandite component of the garnets and the CaO content of the whole rock.

Utilizing the diagram presented by Coleman et.al. (1965), which subdivides eclogitic garnets according to their petrologic setting, the garnet compositions of the Fairbanks eclogites have been plotted in comparison with other analyses from the literature (Fig. 23). Most of the garnets of this study lie within a restricted field defined by Coleman et.al. as typical of garnets from eclogites associated with glaucophane schist terrane. Further references in this text to groups A, B and C eclogites refer to this classification as proposed by the above authors. It is apparent from Fig. 23 that the garnets from the Fairbanks eclogitic rocks are of the group C type eclogite, as characterized by the low pyrope content.

MgO/FeO ratios of the garnets in this study are comparable with those of other group C eclogites, as shown in Figures 24 and 25. Despite

Table 3a. Chemical analyses of constituent garnets.

OXIDES	PELITIC SCHIST		GARNET AMPHIBOLE	ECLOGITIC (Gt-Am-Ct-Oz)					ROCKS Gt-Px-Am-Ct-Qz							
	F70	F71	F136	F50	F86	F89	F93	F99	F39	F75	F78	F80	F92	F100	F101	F201
SiO_2	38.45	38.63	37.30	37.72	38.96	37.86	37.26	37.44	36.72	37.14	37.48	37.89	37.32	37.70	36.28	37.75
TiO_2	1.30	1.44	1.90	2.58	1.58	2.02	1.74	1.58	1.76	1.86	1.68	1.50	1.66	1.80	1.58	1.86
Al_2O_3	21.06	21.13	20.45	20.40	20.68	20.74	20.46	20.88	20.44	20.26	20.16	20.41	20.10	20.45	20.47	20.76
Fe_2O_3	0.56	0.89	0.87	0.64	1.18	0.48	0.89	1.09	1.20	1.30	1.52	3.20	0.88	0.67	1.26	0.92
FeO	28.93	28.25	24.03	21.02	25.04	23.87	26.64	25.34	25.28	25.44	24.47	22.83	25.68	24.07	25.48	21.67
MnO	0.78	0.78	1.00	0.53	0.38	2.09	1.90	0.36	1.61	1.68	2.22	1.23	1.77	1.56	2.91	1.72
MgO	2.49	2.35	2.27	1.73	2.68	1.99	1.41	2.44	1.70	1.65	1.90	2.36	1.65	1.91	1.12	1.99
CaO	6.51	6.70	11.55	15.03	9.75	11.09	10.10	10.40	11.19	10.77	10.69	10.92	11.00	11.44	10.24	13.10
Na_2O	0.07	0.07	0.14	0.09	0.10	0.21	0.11	0.07	0.13	0.09	0.12	0.12	0.10	0.21	0.15	0.13
K_2O	0.05	0.05	0.08	0.05	<0.03	0.03	<0.03	<0.03	<<0.03	0.04	<0.03	<0.03	<0.03	<0.03	<0.03	0.08
P_2O_5	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
H_2O^+	0.14	0.00	0.41	0.18	0.12	0.15	0.10	0.27	0.09	0.00	0.14	0.05	0.15	0.12	0.52	0.20
H_2O^-	<0.02	<0.02	0.03	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02	<0.02	0.03	0.04	0.03
Cr_2O_3	0.012	0.0072	0.028	0.083	0.042	0.012	0.009	0.021	0.004	0.0008	0.010	0.051	0.011	0.01	0.006	0.044
NiO	0.0009	0.0010	0.000	0.0012	0.002	0.001	0.001	0.000	0.001	0.0007	0.0012	0.001	0.001	0.001	0.001	0.001
CO_2	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
TOTAL	100.37	100.32	100.06	100.07	100.61	100.56	100.67	99.94	100.15	100.25	100.44	100.69	100.37	100.00	100.09	100.26

Analyses: H. Haramura and T. Katsura

Table 3b. Chemical and physical parameters of the analyzed garnets.

	PELITIC SCHISTS		AMPHIBOLITE	AMPHIBOLE-RICH VARIANTS					ECLOGITIC ASSEMBLAGES PYROXENE RICH VARIANTS							
	F70	F71	F136	F50	F86	F89	F93	F99	F39	F75	F78	F80	F92	F100	F101	F201
Si^{++++}	6.04	6.07	5.86	5.90	6.05	5.93	5.90	5.89	5.83	5.90	5.92	5.92	5.91	5.95	5.77	5.90
Al^{++++}	0.00	0.000	0.14	0.10	0.00	0.07	0.10	0.11	0.17	0.10	0.08	0.08	0.09	0.05	0.23	0.10
Al^{+++}	3.98	4.04	3.64	3.66	3.88	3.76	3.72	3.76	3.66	3.69	3.67	3.68	3.67	3.75	3.61	3.73
Fe^{+++}	0.7	0.11	0.10	0.08	0.14	0.06	0.11	0.13	0.14	0.16	0.18	0.38	0.11	0.08	0.15	0.11
Ti^{++++}	0.15	0.17	0.22	0.30	0.19	0.24	0.21	0.19	0.21	0.22	0.20	0.18	0.20	0.21	0.19	0.28
Mg^{++}	0.58	0.55	0.53	0.40	0.62	0.46	0.33	0.57	0.40	0.39	0.45	0.55	0.39	0.45	0.27	0.46
Fe^{++}	3.80	3.71	3.16	2.75	3.25	3.13	3.53	3.33	3.36	3.38	3.23	2.98	3.40	3.17	3.39	2.83
Mn^{++}	0.10	0.10	0.13	0.07	0.07	0.28	0.25	0.05	0.22	0.23	0.30	0.16	0.24	0.21	0.39	0.23
Ca^{++}	1.10	1.13	1.94	2.52	1.62	1.86	1.71	1.75	1.91	1.83	1.81	1.83	1.87	1.93	1.75	2.20
Oxygen	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
ALMANDINE	68.07	67.56	54.76	47.89	58.65	54.57	60.52	58.42	57.10	57.98	55.87	54.01	57.70	55.07	58.52	49.54
SPESSARTINE	1.86	1.89	2.31	1.22	0.90	4.84	4.37	0.84	3.68	3.88	5.13	2.95	4.03	3.61	6.77	3.98
PYROPE	10.44	10.02	9.22	7.02	11.19	8.11	5.71	10.02	6.84	6.70	7.93	9.95	6.61	7.79	4.58	8.11
ANDRADITE	1.78	2.87	2.68	1.97	3.73	1.48	2.73	3.39	3.66	4.00	4.69	10.22	2.67	2.07	3.91	2.84
GROSSULAR	17.85	17.66	31.04	41.90	25.53	31.00	26.67	27.32	28.72	27.45	26.58	22.87	29.00	31.46	26.22	35.53
R.I.	1.805	1.801	1.796	1.786	1.794	1.798	1.798	1.796	1.801	1.800	1.794	1.790	1.801	1.796	1.806	1.789
S.G.(calc)	3.97	3.97	3.94	3.88	3.91	3.95	3.95	3.93	3.92	3.93	3.92	3.90	3.93	3.93	3.94	3.89
UNIT CELL, Å	11.708	11.705	11.738	11.749	11.738	11.736	11.727	11.740	11.743	11.745	11.739	11.733	11.744	11.737	11.731	11.747

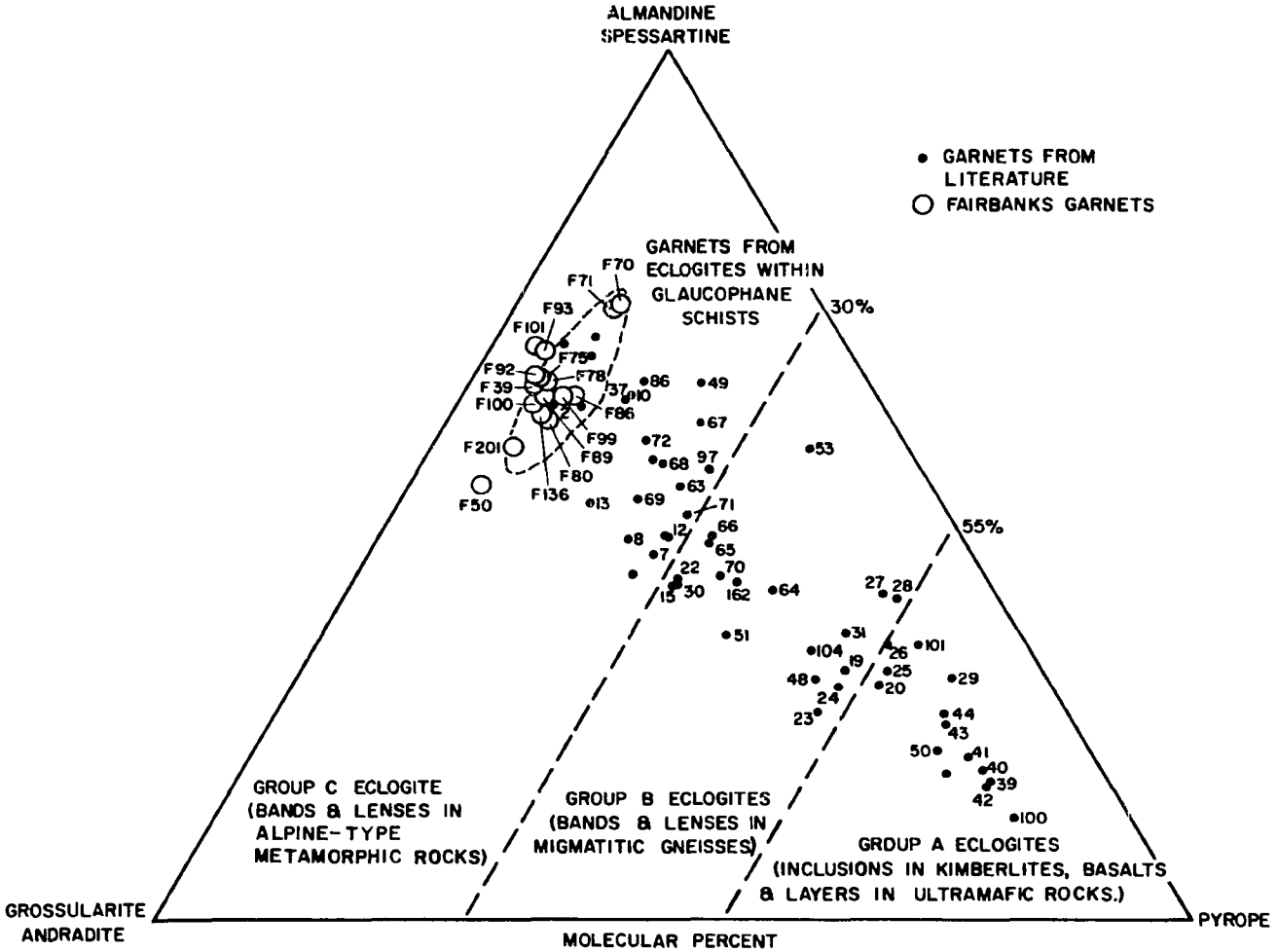


Fig. 23. Comparative chemical composition of the analyses garnets from pelitic schists, amphibolites and eclogites of the Fairbanks area and eclogitic garnets reported by other authors. Diagram adapted from Coleman et.al. (1965).

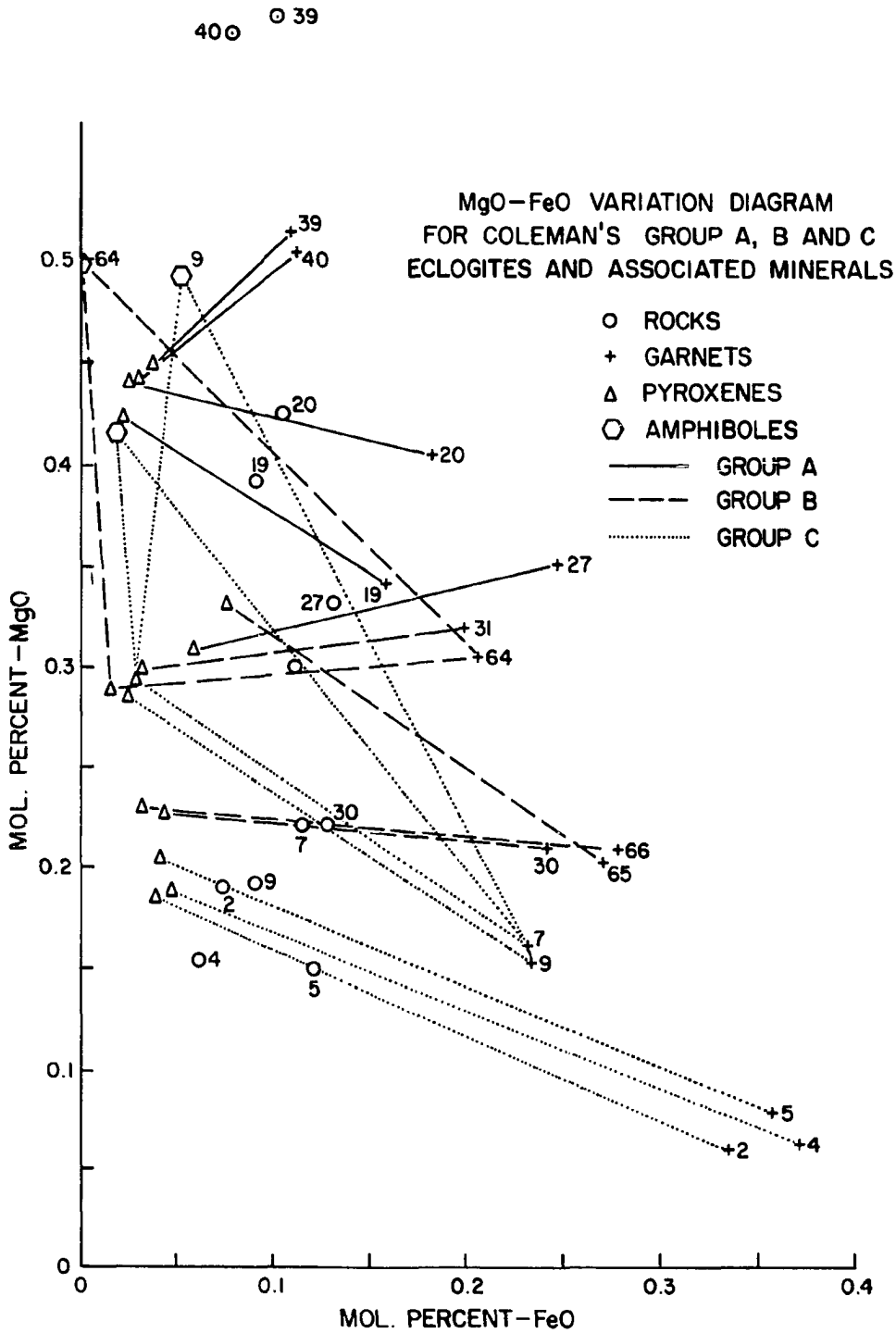


Fig. 24. MgO - FeO variation diagram showing the comparative composition of constituent minerals of selected eclogites reported in the recent literature.

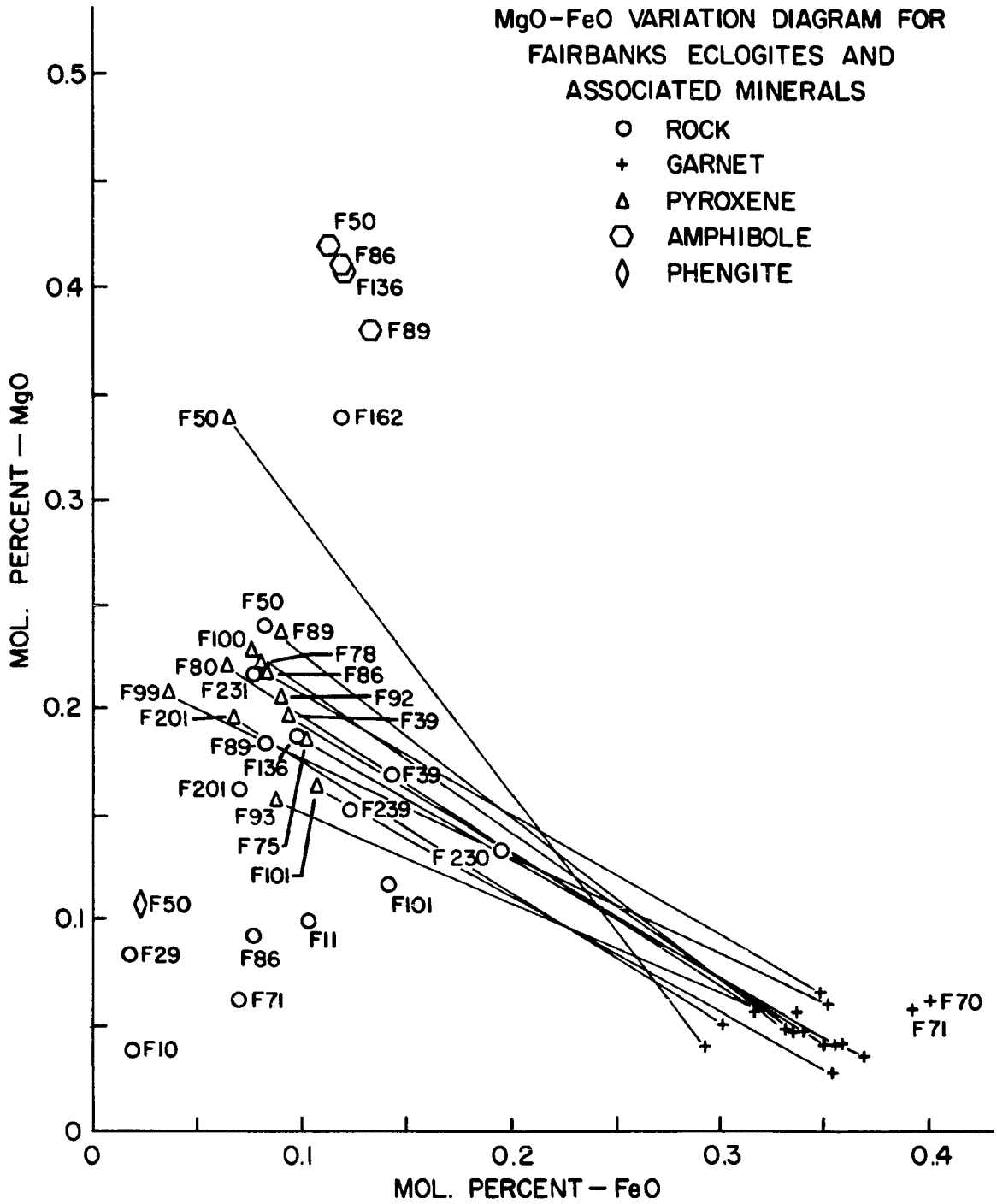


Fig. 25. MgO - FeO variation diagram for the eclogitic rocks and minerals in this study.

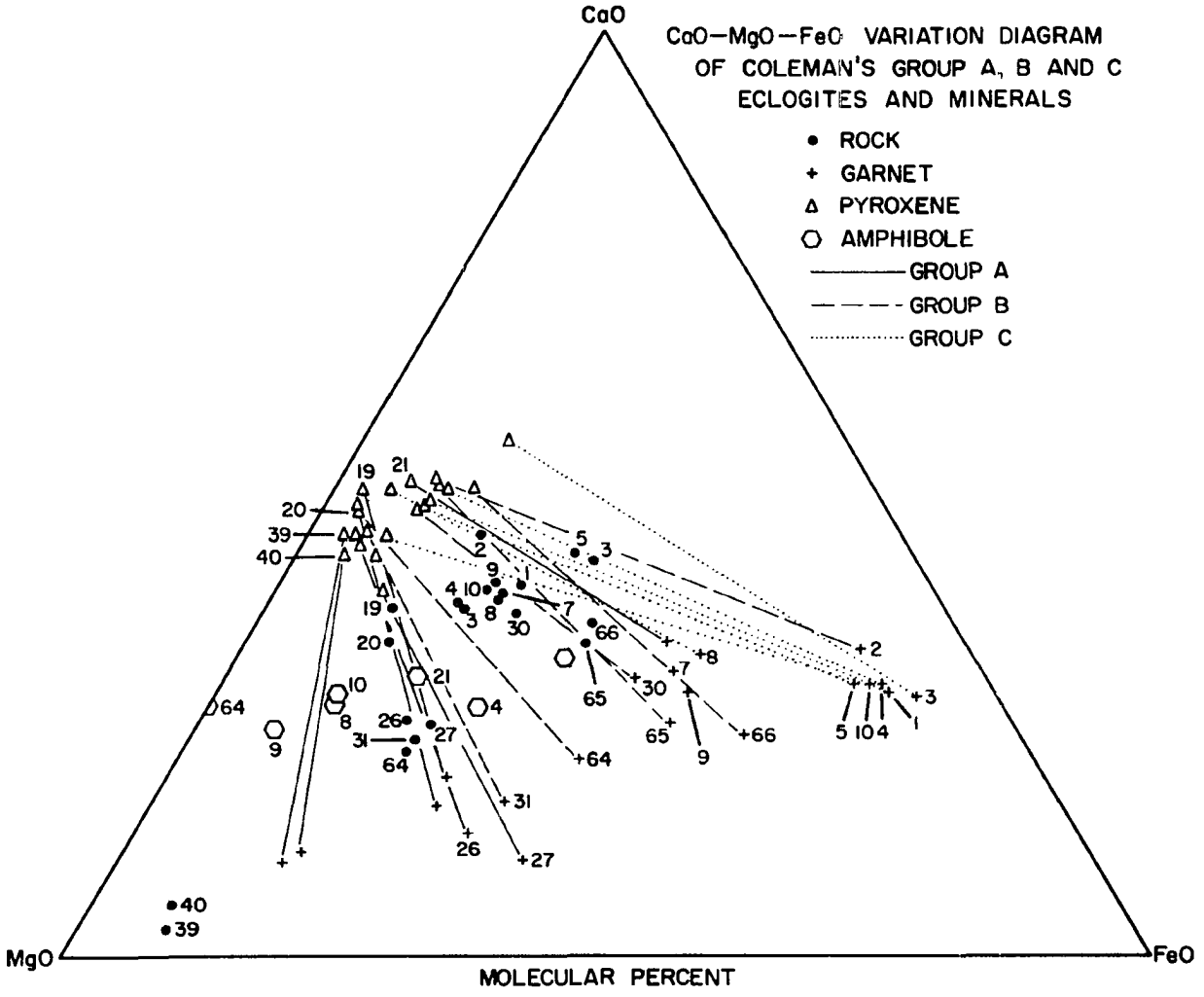


Fig. 26. MgO - FeO - CaO variation diagram for selected eclogitic rocks and minerals reported by other authors.

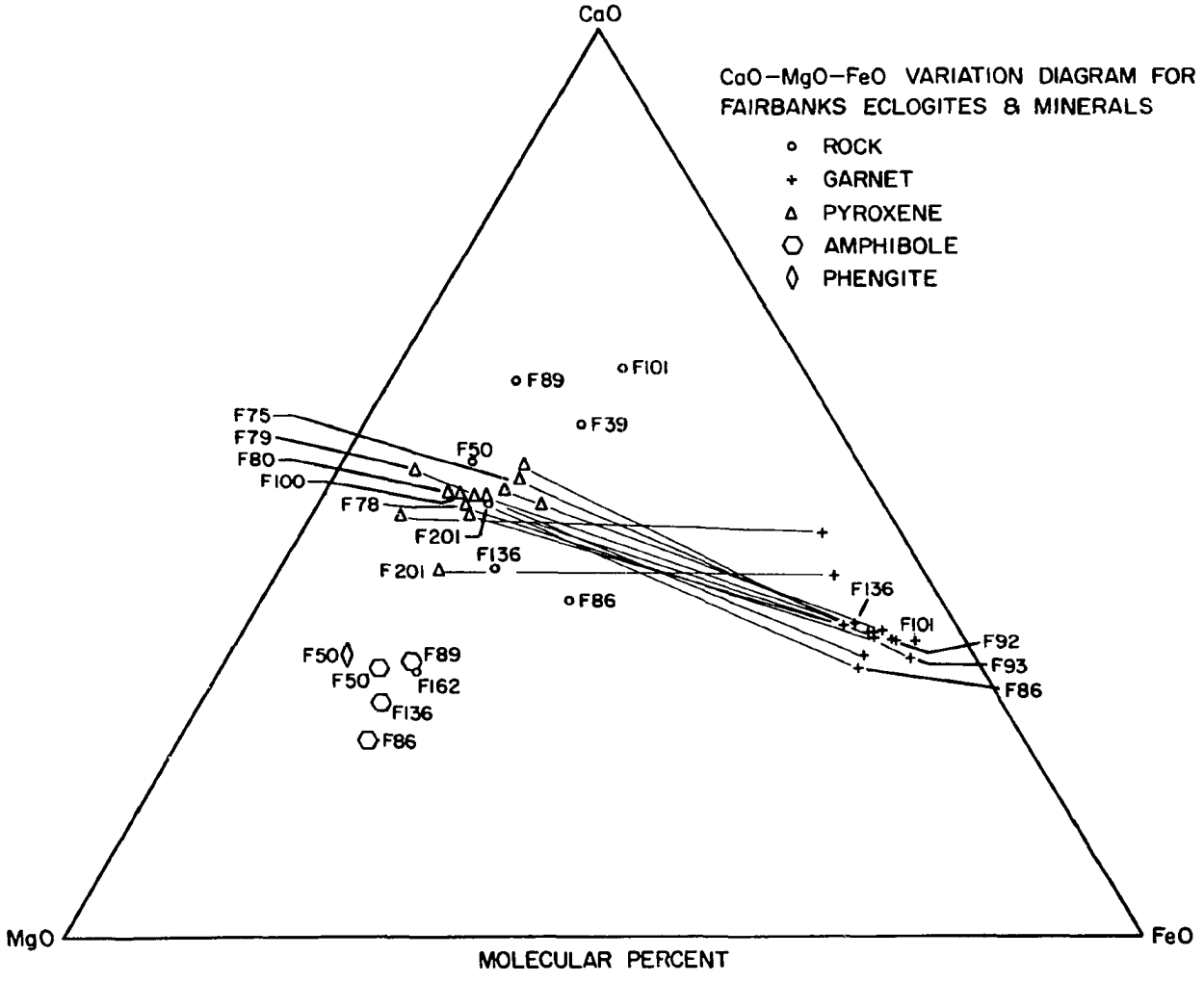


Fig. 27. MgO - FeO - CaO variation diagram for eclogitic rocks and minerals from the Fairbanks area.

the very high bulk CaO content of the parent rocks in the Fairbanks area, there is no significant increase in the CaO content of the garnets as compared with other group C type eclogitic garnets in the CaO-MgO-FeO plots (Figs. 26 and 27).

Clinopyroxenes

Chemical compositions, optical data and molecular end-member recalculations of five clinopyroxenes from garnet-amphibole-clinopyroxene-(± calcite, quartz, plagioclase, "epidote) rocks and eight from garnet-clinopyroxene- (± calcite, quartz, plagioclase, "epidote") rocks are given in tables 4a and 4b. The procedure of White, (1964), as modified by Edgar et al., (1969) was employed in the calculation of the molecular end-member components from chemical analyses.

The Na_2O content of the clinopyroxenes from the eclogitic rocks ranged from 1.54 to 5.92 weight percent, with a mean Na_2O content of 4.55 wt.%. This is slightly higher than the 4 wt.% cited by Yoder (1950) as being typical of eclogitic clinopyroxenes.

Variation in the chemical composition of the clinopyroxenes is greater than that of the coexistent garnets in the Fairbanks eclogites. Tetrahedrally coordinated Al^{+++} is low, and the excess of Al^{+++} is calculated for the octahedral site. After the formation of jadeite the excess of octahedrally coordinated Al^{+++} is combined with Ca^{++} to form the Tschermak's molecule. The Fe^{+++} content of the clinopyroxenes is low causing the relatively low percentage of the acmite molecule.

The nomenclature and compositional variation of clinopyroxenes in eclogitic rocks have been recently discussed by White, (1964), and Green and Ringwood, (1966); and as noted by Vogel, (1967), there has been a

Table 4a. Chemical analyses of clinopyroxenes.

	Amphibole - Rich Variants					Pyroxene - Rich Variants							
Oxide	F50	F86	F89	F93	F99	F39	F75	F78	F80	F92	F100	F101	F201
SiO_2	52.20	53.48	52.21	51.45	54.28	52.19	52.28	54.13	54.40	52.38	53.49	51.61	58.09
TiO_2	0.92	0.25	0.61	0.50	0.22	0.90	0.42	0.20	0.22	0.48	0.54	0.34	0.32
Al_2O_3	3.64	6.57	6.32	8.65	12.50	5.89	7.49	7.39	8.63	7.16	7.59	8.85	11.95
Fe_2O_3	0.50	2.13	1.70	4.44	1.42	2.81	1.80	1.48	1.38	2.76	2.02	2.48	1.54
FeO	4.65	5.86	6.35	6.13	2.48	6.66	7.22	5.68	4.51	6.39	5.41	7.67	4.77
MnO	0.01	0.06	0.06	0.05	0.01	0.02	0.04	0.06	0.04	0.06	0.05	0.04	0.15
MgO	13.63	8.86	9.48	6.30	8.29	7.89	7.42	8.96	8.87	8.32	9.14	6.57	7.87
CaO	19.30	15.70	15.67	14.60	14.38	15.73	15.99	15.09	15.19	15.56	15.70	13.62	9.80
Na_2O	1.54	4.68	4.63	5.84	5.04	4.84	4.92	4.76	5.15	4.96	4.64	5.92	3.34
K_2O	0.09	0.03	<0.02	<0.03	0.04	0.04	0.05	<0.02	<0.02	<0.02	0.04	<0.03	0.11
P_2O_5	0.00	0.00	0.00	0.05	0.10	0.00	0.00	0.00	0.00	0.00	0.15	0.07	0.10
H_2O^+	2.85	2.21	2.62	1.80	1.22	2.76	2.23	1.96	1.70	2.02	1.46	2.55	1.35
H_2O^-	<0.02	0.04	0.09	0.06	t.c.	0.02	0.07	0.04	0.06	0.07	t.c.	0.02	t.c.
Cr_2O_3	0.018	0.009	0.01	0.02	0.021	0.005	0.016	0.014	0.02	0.01	0.01	0.01	0.055
NiO	0.003	0.001	0.002	0.003	0.003	0.000	0.003	0.002	0.003	0.002	0.001	0.001	0.001
CO_2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TOTAL	99.71	99.88	99.77	99.94	100.00	99.76	99.93	99.79	100.19	100.19	100.24	100.08	99.75

Analyses: H. Haramura and T. Katsura

Table 4b. Chemical and physical parameters of constituent clinopyroxenes.

	AMPHIBOLE-RICH VARIANTS					PYROXENE-RICH VARIANTS							
	F50	F86	F89	F93	F99	F39	F75	F78	F80	F92	F100	F101	F201
Si^{++++}	1.97	1.99	1.97	1.92	1.95	1.98	1.98	2.00	1.99	1.96	1.97	1.95	2.00
Al^{IV}	0.03	0.01	0.03	0.08	0.05	0.02	0.02	0.00	0.01	0.04	0.03	0.05	0.00
Al^{VI}	0.13	0.28	0.26	0.30	0.48	0.25	0.31	0.32	0.36	0.28	0.30	0.36	0.50
Fe^{+++}	0.02	0.06	0.06	0.13	0.04	0.08	0.04	0.04	0.04	0.08	0.06	0.07	0.04
Ti^{++++}	0.03	0.01	0.02	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.02	0.00	0.01
Fe^{++}	0.15	0.18	0.20	0.19	0.07	0.21	0.23	0.18	0.14	0.20	0.17	0.24	0.14
Mn^{++}	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg^{++}	0.77	0.49	0.53	0.35	0.44	0.45	0.42	0.49	0.48	0.46	0.50	0.37	0.42
Ca^{+}	0.78	0.63	0.63	0.59	0.55	0.64	0.65	0.60	0.60	0.62	0.62	0.55	0.37
Na^{+}	0.11	0.34	0.33	0.42	0.35	0.34	0.35	0.34	0.37	0.36	0.33	0.43	0.23
K^{+}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxyger	6	6	6	6	6	6	6	6	6	6	6	6	6
$Na^{+}/Na^{+} + Ca^{++}$	0.12	0.35	0.33	0.41	0.38	0.35	0.35	0.33	0.36	0.36	0.33	0.43	0.38
$Al^{IV}/Al^{IV} + Fe^{+++}$	0.86	0.82	0.81	0.69	0.92	0.80	0.88	0.88	0.90	0.82	0.88	0.89	0.88
ACMITE	2.00	6.05	5.90	12.90	4.30	8.00	3.98	4.08	4.04	4.08	6.06	6.86	5.18
JADEITE	9.20	28.21	26.60	28.78	33.20	26.10	30.90	30.61	33.33	28.57	27.27	35.29	24.59
TSCHERMAK'S	3.60	0.50	0.90	4.50	11.80	1.00	0.90	1.00	2.02	2.00	3.03	2.20	20.06
ENSTATITE	39.39	24.70	26.10	17.40	23.60	23.10	20.90	25.00	24.24	24.49	25.25	18.13	27.18
FERROSILITE	7.70	9.10	9.90	9.40	3.70	10.60	11.42	9.24	7.07	10.21	8.59	11.76	9.06
WOLLASTONITE	38.11	31.50	30.50	27.04	23.60	31.70	31.80	30.10	29.20	30.61	29.80	25.74	13.91
a (Å)	9.478	9.625	9.684	9.592	9.569	9.554	9.610	9.611	9.627	9.625	9.585	9.661	9.659
b (Å)	9.077	8.822	8.920	8.798	8.781	8.803	8.813	8.809	8.814	8.500	8.786	8.738	8.670
c (Å)	5.206	5.264	5.028	5.265	5.255	5.239	5.263	5.256	5.270	5.235	5.248	5.297	5.373
β, degrees	105°41'	106°48'	108°14'	106°46'	106°56'	105°23'	106°38'	106°30'	106°47'	106°19'	106°38'	107°29'	108°08'
V (Å^3)	447.9	447.0	434.3	444.3	441.6	440.6	445.7	445.0	447.2	428.28	441.9	447.2	449.9
R.I. α	1.670	1.680	1.684	1.686	1.674	1.677	1.673	1.678	1.674	1.684	1.682	1.680	1.693
R.I. β	1.686	1.692	1.692	1.695	1.692	1.686	1.688	1.692	1.688	1.693	1.692	1.694	1.710
R.I. γ	1.694	1.698	1.696	1.699	1.699	1.699	1.694	1.697	1.693	1.697	1.696	1.698	1.716
2V	74	70	70	74	71	76	64	65	68	63	71	69	75

tendency towards a "closed-circuit definition", whereby pyroxenes from eclogites are named omphacite, and where eclogite is defined as a rock consisting essentially of "omphacite" and pyrope garnet.

Clarke and Papike, (1968), suggest that the term omphacite be reserved for clinopyroxenes in which $0.2 < Na/(Na + Ca) < 0.8$ and $Al/(Al + Fe)^{+++} > 0.5$, where only octahedrally coordinated Al is considered. On this basis all but one of the clinopyroxenes from the Fairbanks eclogites are true omphacites, ($Na/(Na + Ca) = 0.33 - 0.43$, and $Al/(Al + Fe) = 0.69 + 0.90$.).

The clinopyroxene from the garnet-pyroxene-amphibole-calcite-quartz-plagioclase-clinozoisite rock, (F50), has $Na/Na + Ca = 0.12$, and tetrahedrally coordinated $Al/Al + Fe = 0.015$. According to Clarke and Papike's proposal, this would be an aluminous diopside.

White, (1964), showed that the clinopyroxenes from eclogitic rocks have a Jadeite: Tschermak/s Molecule ratio $> \frac{1}{2}$. Figure 28 shows that all of the clinopyroxenes from the Fairbanks eclogites do indeed fulfill this condition. The high jadeite content of the Fairbanks omphacites is typical of group C eclogites. The high proportion of the Tschermak's molecule in two of the Fairbanks omphacites reflects the excess of calculated Al^{VI} over that necessary to form the Jadeite molecule. (Basically this suggests that the alumina is predominantly in the octaheral rather than the tetrahedral site.) This relationship was also noted for the clinopyroxenes from the Franciscan eclogites by Coleman et.al., (1965).

Figure 28, adapted from Coleman et.al., compares the omphacites from the Fairbank's eclogites with those from eclogites studied by other authors with respect to the molecular end-members Jadeite-Acmite-(Diopside + Hedenbergite + Tschermak's molecule). The variation in the substitution of

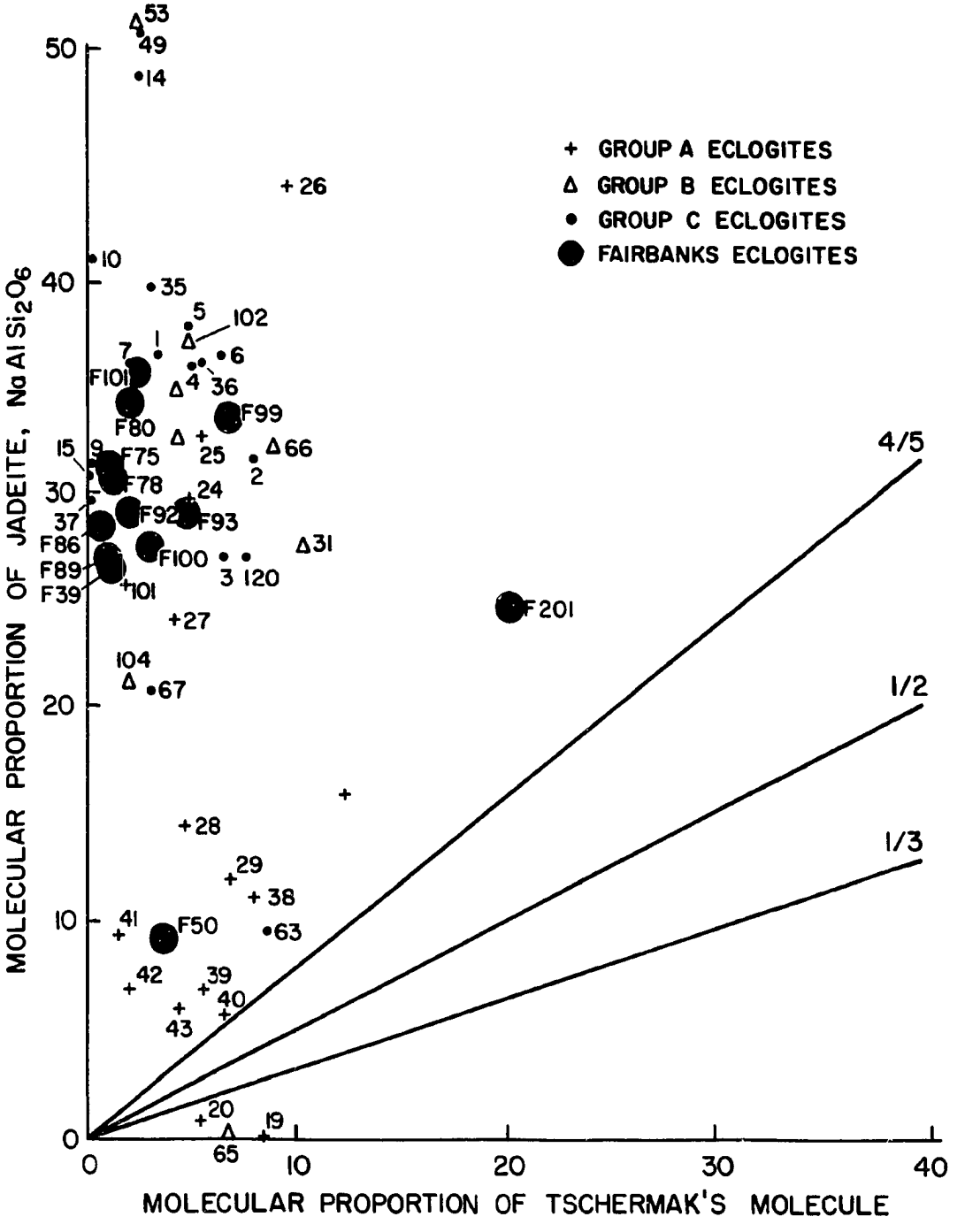


Fig. 28. Jadeite-Tschermak's molecule variation diagram, after White, (1964), showing the composition of omphacitic pyroxenes from the Fairbanks eclogites as compared to those from type A, B and C eclogites.

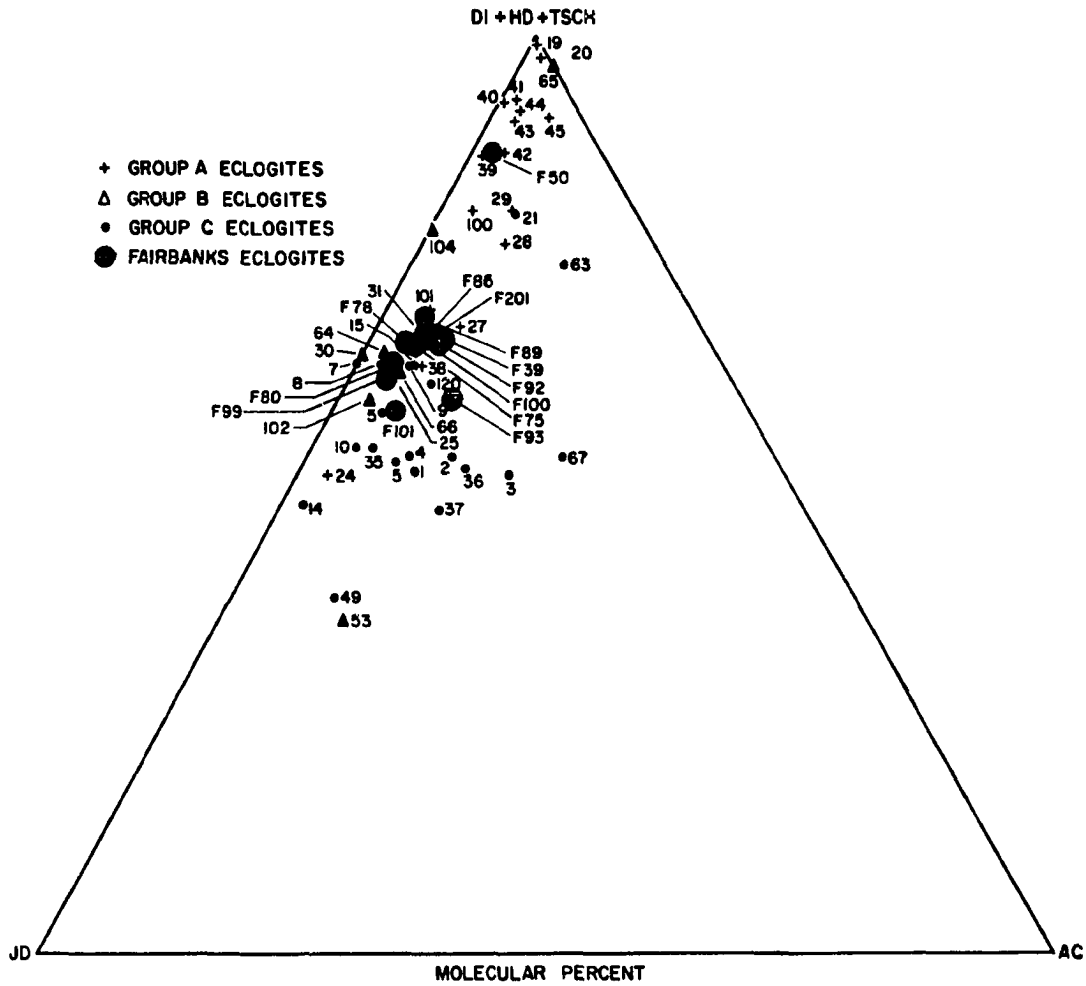


Fig. 29. Jd-Ac-(Di+Hd+Tsch) variation diagram for analyzed omphacitic pyroxenes from the study as compared to those reported in the recent literature, (after Coleman et.al. 1965).

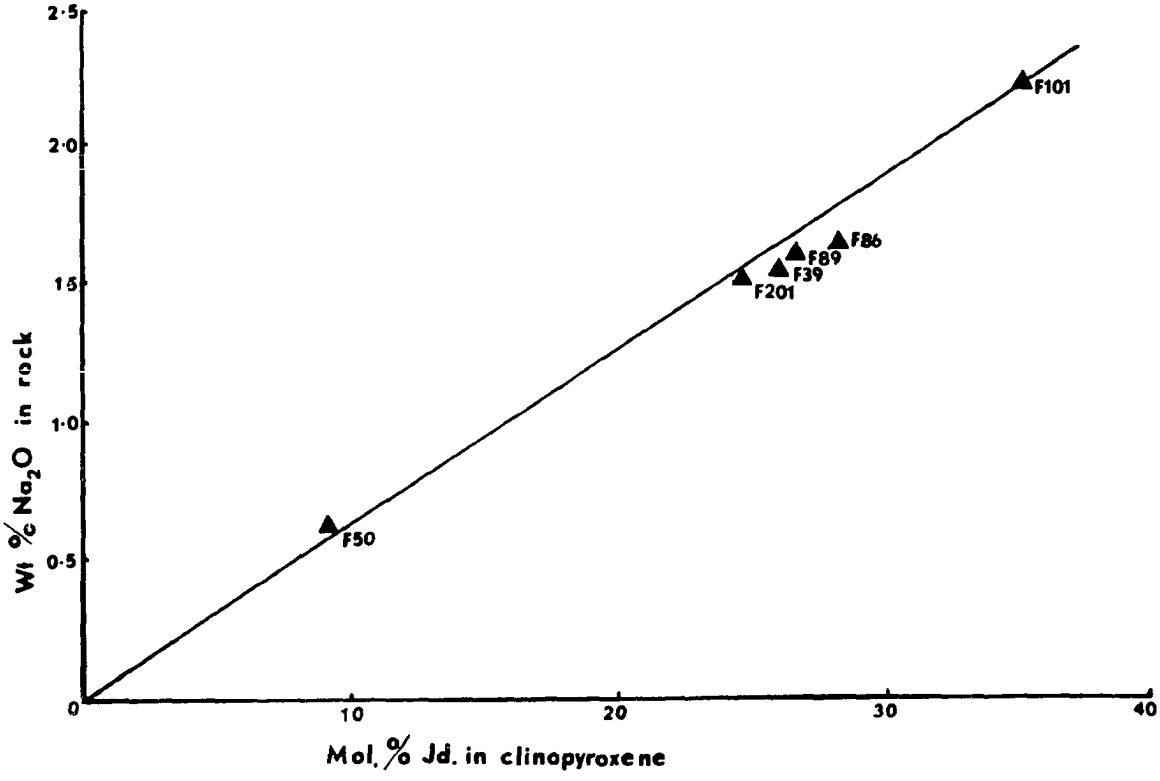


Fig. 30. Variation diagram showing interdependence of the whole rock Na_2O content and the jadeite content of the constituent clinopyroxene.

Acmite for (Jd. + Di. + Hd: + Tsch.) is less in the Fairbanks omphacites than in comparable omphacites and omphacitic chloromelanites. This fact could be interpreted as a function of low partial pressures of oxygen, which would tend to lower the Fe^{+++}/Fe^{++} ratio during recrystallization.

As shown in the MgO-FeO-CaO diagrams, (Figs. 26 and 27), there is little CaO-enrichment of the omphacites from the Fairbanks eclogites as compared to the clinopyroxenes from less calcic group C eclogites as reported by Coleman et.al. (op. cit.).

Figure 30 shows the interdependence of the jadeite component of the omphacitic pyroxenes from the Fairbanks eclogites with the Na_2O content of the whole rock. Coleman et.al. note that the sodium content of the group C eclogites is higher than that of pyroxenes from groups A and B, and these authors relate the high jadeite content to the bulk composition of the group C eclogites.

Lattice parameters are comparable to those of other eclogitic omphacites reported by Clarke and Papike, (1967), but the cell volumes are somewhat greater than those of typical omphacitic pyroxenes.

Amphiboles

One amphibole from a garnet-amphibole-calcite-biotite-plagioclase rock and three from garnet-omphacite-amphibole-(± quartz, calcite, albite, "epidote") rock were separated for chemical analysis. Chemical and pertinent optical data are presented in table 5. Variations in optical properties within individual grains limits the usefulness of optical data.

Ernst, (1968), classifies amphiboles on the basis of the predominant location in the X site. All of the analyzed amphiboles from the Fairbanks calc-magnesian rocks are, in these terms, calcic amphiboles. Mg^{++} and Na^{+} are subordinate components of this M_4 structural site.

Table 5. Chemical analyses of amphiboles and mica.

OXIDE	Garnet-Amphibole Rock	Garnet-Amphibole-Pyroxene-Carbonate-Quartz Rock			
	Amphibole	Amphiboles			Phengite
	F136	F50	F86	F89	F50
SiO_2	52.71	51.50	54.25	51.60	47.15
TiO_2	0.24	0.48	0.22	0.21	1.32
Al_2O_3	5.14	5.47	5.25	5.76	24.78
Fe_2O_3	1.80	0.60	1.77	1.57	0.84
FeO	8.61	8.01	8.50	9.55	1.50
MnO	0.05	0.05	0.04	0.16	0.01
MgO	16.45	16.94	16.63	15.20	4.32
CaO	10.32	12.62	8.63	12.00	3.30
Na_2O	1.71	1.52	1.83	1.76	0.30
K_2O	0.47	0.28	0.47	0.18	9.32
H_2O^-	0.00	0.05	0.05	0.00	0.05
H_2O^+	2.69	2.74	2.39	2.50	7.02
P_2O_5	tr	tr	tr	tr	tr
Cr_2O_3	0.009	0.045	0.010	0.008	0.110
NiO	0.001	0.001	0.012	0.002	0.000
TOTAL	100.200	100.306	99.802	100.500	100.020
R.I. α	1.617	1.620	1.624	1.626	1.563
R.I. γ	1.628	1.632	1.633	1.636	1.596
R.I. β	1.640	1.641	1.643	1.648	1.598
$2V_\gamma$	74	72	80	84	
	17	16	24	26	@ 16°
Si^{++++}	7.8210	7.6700	7.9970	7.7000	
Al^{+++}	0.1790	0.3300	0.0030	0.3000	
Ti^{++++}	0.0270	0.0570	0.0250	0.0230	
Al^{+++}	0.8818	0.6305	0.9042	0.7140	
Fe^{+++}	0.1910	0.0661	0.1940	0.1760	
Fe^{++}	1.0690	0.9960	1.0390	1.1910	
Mn^{++}	0.0050	0.0052	0.0500	0.0210	
Mg^{++}	3.6420	3.7540	2.6234	3.3789	
Na^{+}	0.4930	0.4380	0.5176	0.5010	
Ca^{++}	1.6410	2.0110	1.3252	1.9180	
K^{+}	0.0900	0.0540	0.0890	0.0330	
H_2O^{+}	2.6427	2.6826	2.3267	2.4572	
H_2O^{-}	0.0000	0.0510	0.0507	0.0000	

ANALYSES: H. Haramura and T. Katsura

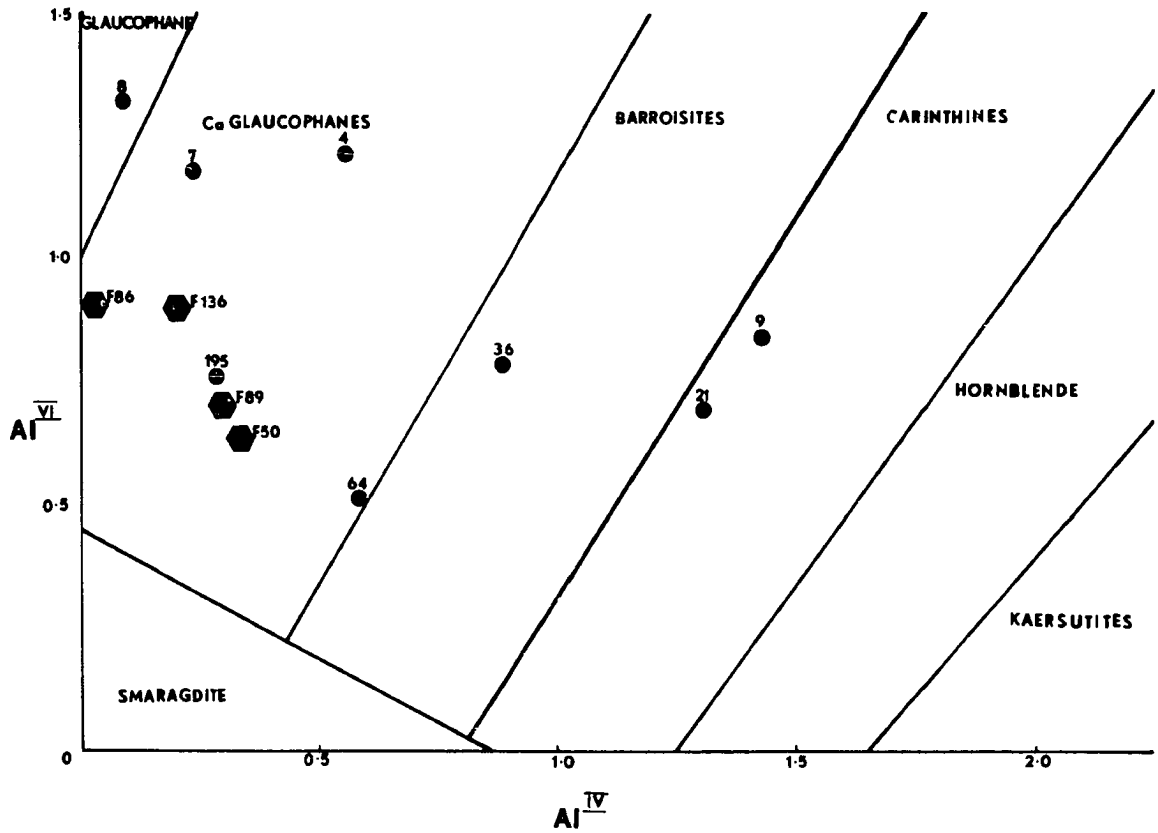


Fig. 31. Aluminium coordination diagram, after Mottana et.al. (1970), with plots of amphiboles from this study as compared to selected eclogitic amphiboles.

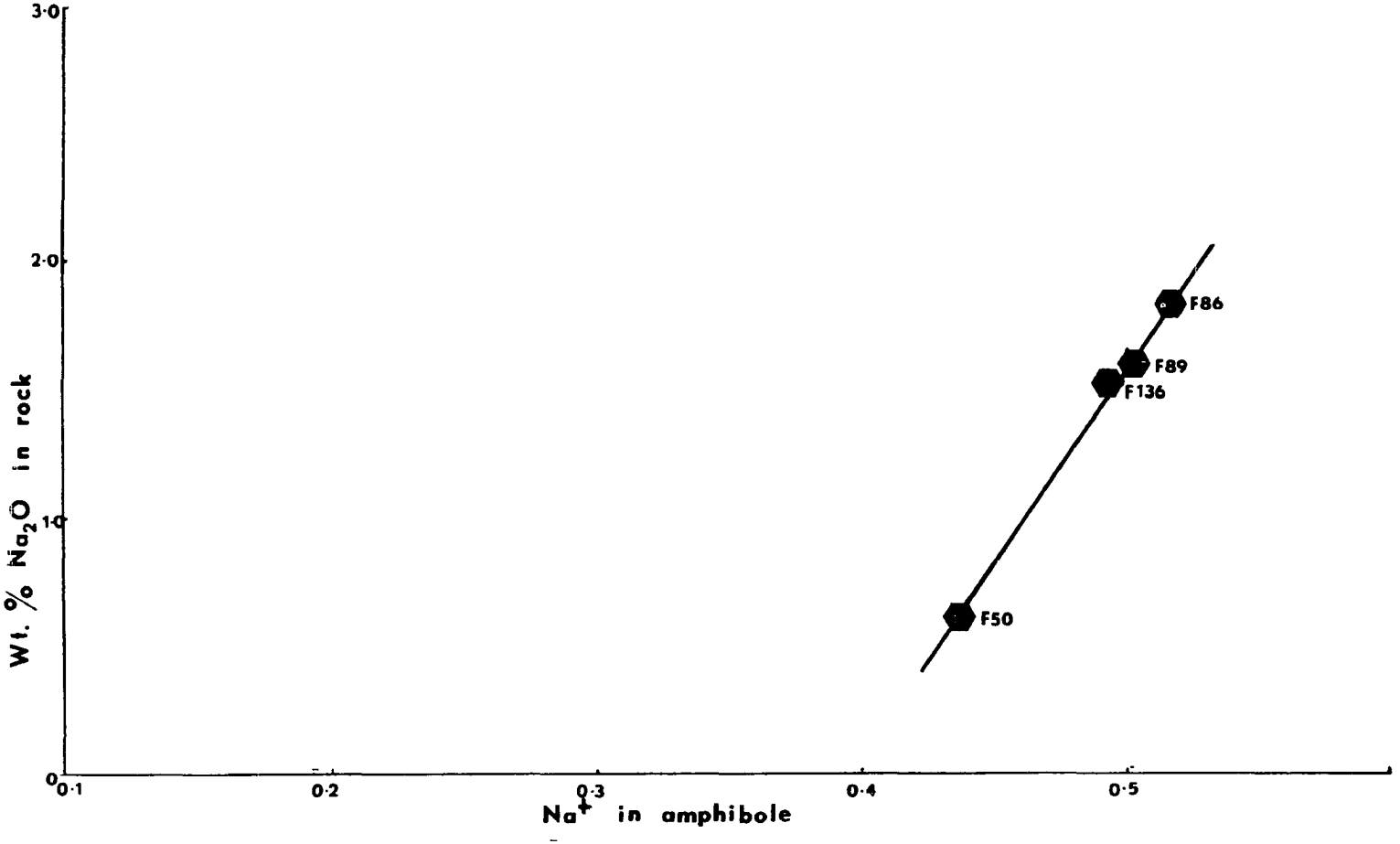


Fig. 32. Variation diagram showing correlations between whole rock and constituent amphibole Na content.

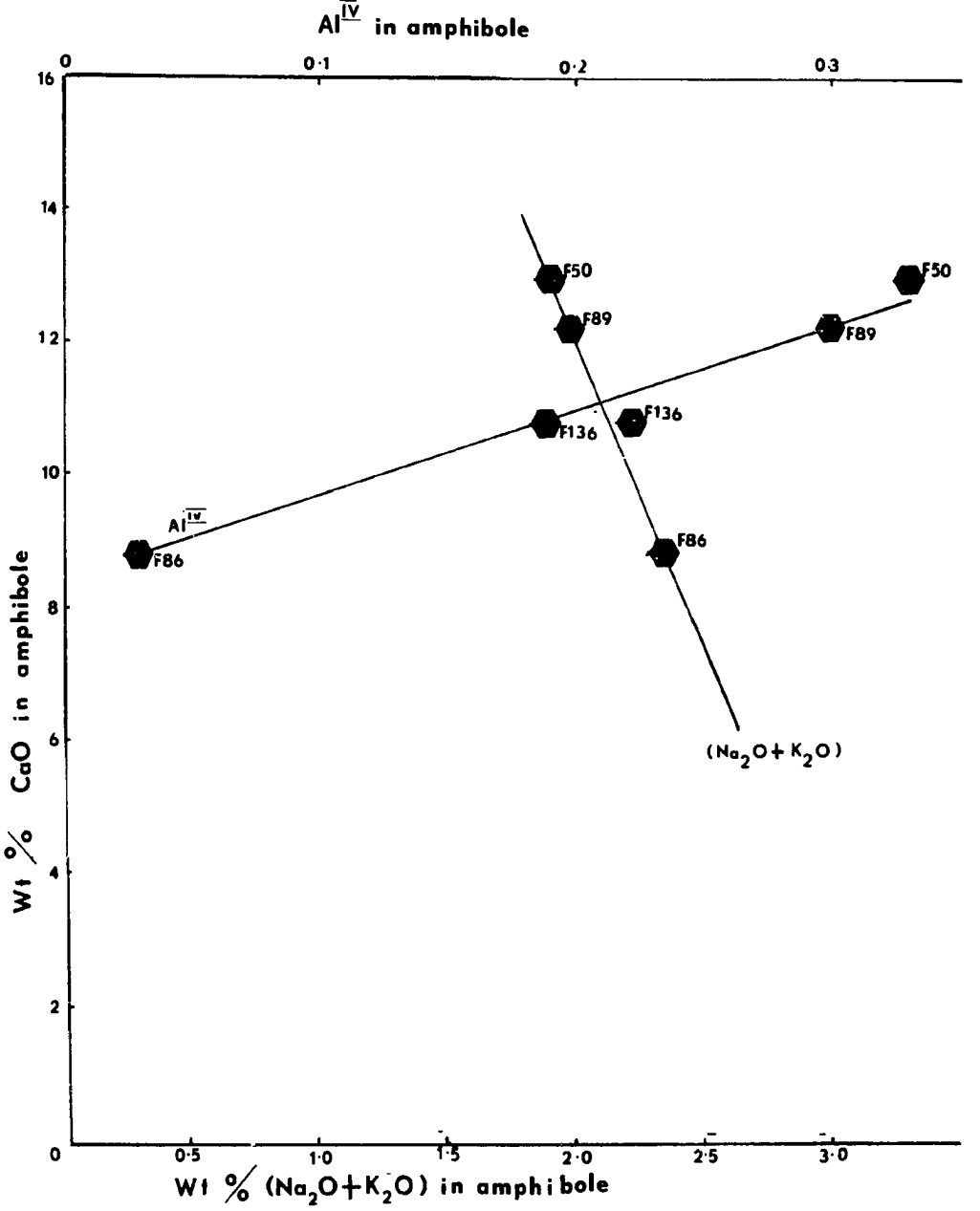


Fig. 33. Variation diagram showing the covariant relation between $Na_2O + K_2O$ and CaO and Al^{IV} and CaO content of amphiboles from the eclogitic rocks in this study.

Mottana et al. (1970), have classified amphiboles from eclogites on the basis of the ratio of tetrahedrally to octahedrally coordinated Al^{+++}. Figure 31 shows that all of the analyzed amphiboles from the study area are calcic-glauciophanes according to their nomenclature; and are similar to amphiboles from amphibolite facies or glaucophane schist facies eclogites.

Deer, Howie and Zussman's (1963) classification suggests that the amphiboles from the Fairbanks eclogites are members of the tremolite-edenite series, with a significant amount of FeO in the Y site. The most similar amphiboles from the literature are the calcic amphiboles from eclogites in the Carabobo area of Venezuela, as described by Morgan, (1967).

In this paper we shall refer to the amphiboles from the Fairbanks eclogitic rocks as calcic amphiboles to avoid confusion of these low-sodium minerals with glaucophane sensu strictu.

Substitution of tetrahedrally coordinated Al^{+++} for Si^{++++} is minor in these amphiboles, which, according to Leake, (1965) suggests low pressures of crystallization. Figure 32 shows the strong covariance between CaO and Al^{IV} and the inverse covariance between CaO and $(Na_2O + K_2O)$. As with the coexistent omphacites, the Na_2O content of the analyzed amphiboles appears to be related to the Na_2O content of the host rock, (Fig. 33).

Mica

One colourless mica from a garnet-clinopyroxene-amphibole-calcite-quartz rock, (F50), was separated for chemical analysis. The analysis is listed in table 5. Petrographic relations indicate that the mica is an apparent essential phase of the synkinematic assemblage, and no secondary mica was observed in this rock.

The K_2O-content of the mica is lower than that of most muscovites, and the CaO content is considerably higher. This mica is a phengite similar to that reported by Ernst, (1963), from a glaucophane-chlorite-epidote-sphene-quartz schist from the Kotu district of Shikoku, Japan.

Lambert, (1959), noted a progressive change from phengite to muscovite with increasing metamorphism in the greenshist facies Moinian rocks of Invernesshire; and Ernst, (1963), concluded that high P_{H_2O} is essential to the stability of phengite in the glaucophane schist facies rocks.

Other minerals

Calcite is abundant in most of the eclogitic rocks. X-ray diffraction data show little solid solution with $MgCO_3$. No aragonite was detected in any of the rocks.

Clinozoisite is the most common epidote group mineral in the calcite-bearing eclogitic rocks, but zoisite is also present in the less calcic variants. Iron-rich epidote is present in variable amounts in the more siliceous eclogites and orthite, (allanite), occurs as an accessory in many of the eclogitic rocks.

Rutile is the titaniferous phase in the garnet-amphibolites and in the more siliceous eclogites, while sphene, often mantling rutile cores, is present in the calcareous eclogites.

VARIATION DIAGRAMS

Diagrams showing the variation of two or three oxides in eclogitic rocks and their constituent minerals have been employed in the discussion of petrogenesis by Yoder and Tilley, (1962), Coleman et al. (1965), Church,

(1968), and many other workers. In these diagrams the line joining the coordinates of two coexistent mineral phases is known as a tie-line.

If a rock is bimineralic, then the bulk rock composition will fall upon the tie-line joining the compositions of the two coexistent phases, and if trimineralic the bulk composition will fall within the triangle formed by the tie-lines joining the three coexistent phase, providing the phases contain the oxides being considered. If a rock is subjected to varying conditions of temperature and pressure, then the distribution of the oxides between coexisting mineral phases often changes in a regular manner.

For a bimineralic rock, in terms of the oxides considered, increasing temperature and pressure will result in the pivoting of the tie-lines between the coexisting minerals about the coordinated of the whole rock composition. Bimineralic rocks of different bulk chemistry but having the same coexisting mineral phases will have, at the same pressure and temperature, parallel tie-lines. Combination of these two simple cases will result in a general sweep of the tie-lines across the diagram. Atherton, (1960) discusses the petrogenetic implications of the tie-lines.

It must be stressed that these diagrams consider only the variation of two or three oxides generally, and the presence of another mineral phase containing any of the oxides, or the presence of another oxide which may alter the partitioning of the oxides considered, will result in greater complexity.

MgO:FeO variation diagrams, Figs. 24 and 25 compare the Fairbanks eclogites and their constituent garnets and omphacites with other eclogites selected from the literature. The groups A, B and C are designated after Coleman et al. (1965), and the numbers refer to the key in Appendix 2.

Truly bimineralic eclogites are rare in terms of MgO and FeO, being almost exclusively present in the deep-seated group A types. The slope and the total MgO content of the garnet-omphacite tie-lines of the Fairbank's eclogites very definitely characterizes them as of the group C type.

Yoder and Tilley (1962) and Coleman et al. (1965) stress the fact that in a CaO-MgO-FeO diagram the garnet-clinopyroxene tie-lines for the groups A, B and C eclogites pivot about the compositional field of the clinopyroxenes forming a sweeping field across the diagram. They also note the sub-parallelism of the tie-lines for a given group.

A number of eclogites and their constituent garnets and pyroxenes are plotted in a CaO-MgO-FeO diagram, Fig. 26, and the Fairbank's eclogites and their constituent minerals are shown in Fig. 27. The highly gradational sweep in Fig. 25 obviously reflects the much greater variation of the garnets, particularly in the MgO component, compared with the clinopyroxenes. It is noticeable that the presence of coexistent amphibole affects the composition of the coexistent garnet more than the coexistent clinopyroxene.

While the Fairbank's eclogites are again more comparable with the group C type eclogites, the whole rock compositions are commonly on the CaO-rich side of the garnet-omphacite tie-lines, in contrast to the majority of other group C eclogites.

A number of other variation diagrams were constructed, but none were as useful in differentiating between the three groups of eclogites as those presented above. In all cases, the calc-eclogites of the Fairbank's area could only be considered as group C type eclogites.

DISTRIBUTION COEFFICIENTS

Saxena, (1968), studied the distribution coefficient of Fe between coexistent garnets and clinopyroxenes from a variety of metamorphic rocks. Eclogites from glaucophane-schist facies metamorphites have $K_{DFe}^{Gt-Cpx} = 0.044$, and from granulites = 0.138. Eclogitic rocks of other facies gave results which are difficult to interpret.

He notes that the effect of CaO in high grade metamorphics is dominantly dilution, and does not seriously alter the nearly ideal solution of MgO in FeO. K_{DFe} decreases with increasing MnO content in the garnet. In studying the effect of pressure and temperature upon the distribution coefficient he concludes that temperature is the controlling factor.

Saxena's data, supplemented by additional data from the literature are plotted in Fig. 34 together with data from the Fairbanks eclogites. The method of plotting $K_{D(Fe)}^{Cpx-Gt}$, where X_{Fe} is the mole fraction of Fe, = Fe/Fe + Mg in the clinopyroxene and garnet respectively, presents ideal solutions as straight lines rather than curves.

Distribution coefficients for the Fairbank's eclogites are somewhat scattered about 0.044, indicating that pressures were in the order of 5-10Kb., (Essene et al. 1965). These authors suggest temperatures of 150-300 degrees for the Franciscan glaucophane schists, so it is possible that the slightly higher values of the $K_{D(Fe)}^{Cpx-Gt}$ in the Fairbank's eclogites are due to higher temperatures.

The mole fraction of Mg, Mg/Mg + Fe + Ca was calculated for a number of eclogites and their constituent minerals. These are designated as X_{Rock}^{Mg}, X_{Cpx}^{Mg}, X_{Gt}^{Mg} and $X_{Amph.}^{Mg}$ for the rock, clinopyroxene, garnet and

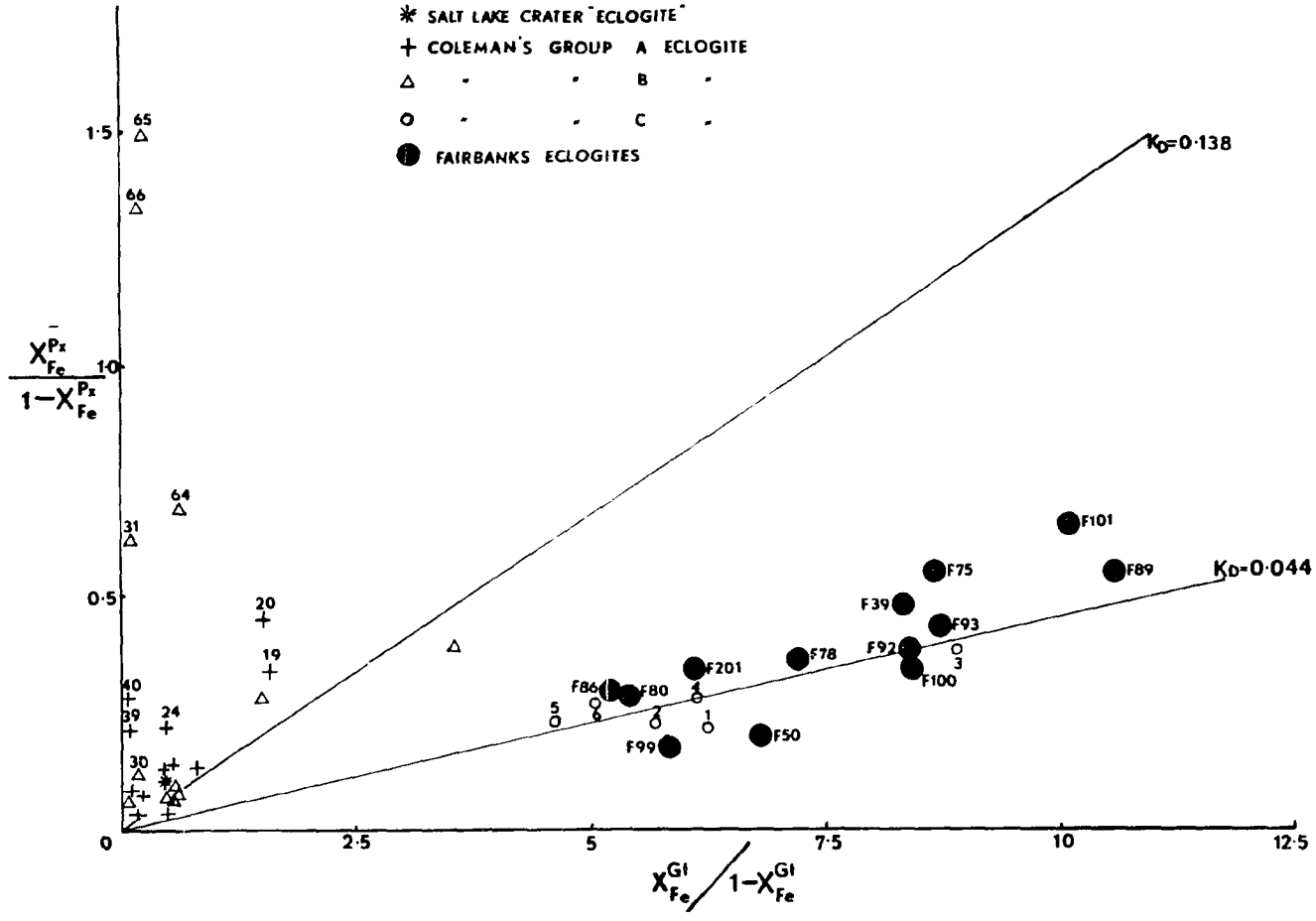


Fig. 34. Diagram illustrating Fe partition relations between coexistent garnet and omphacite from the Fairbanks and selected eclogites discussed by other authors. After Saxena (1968).

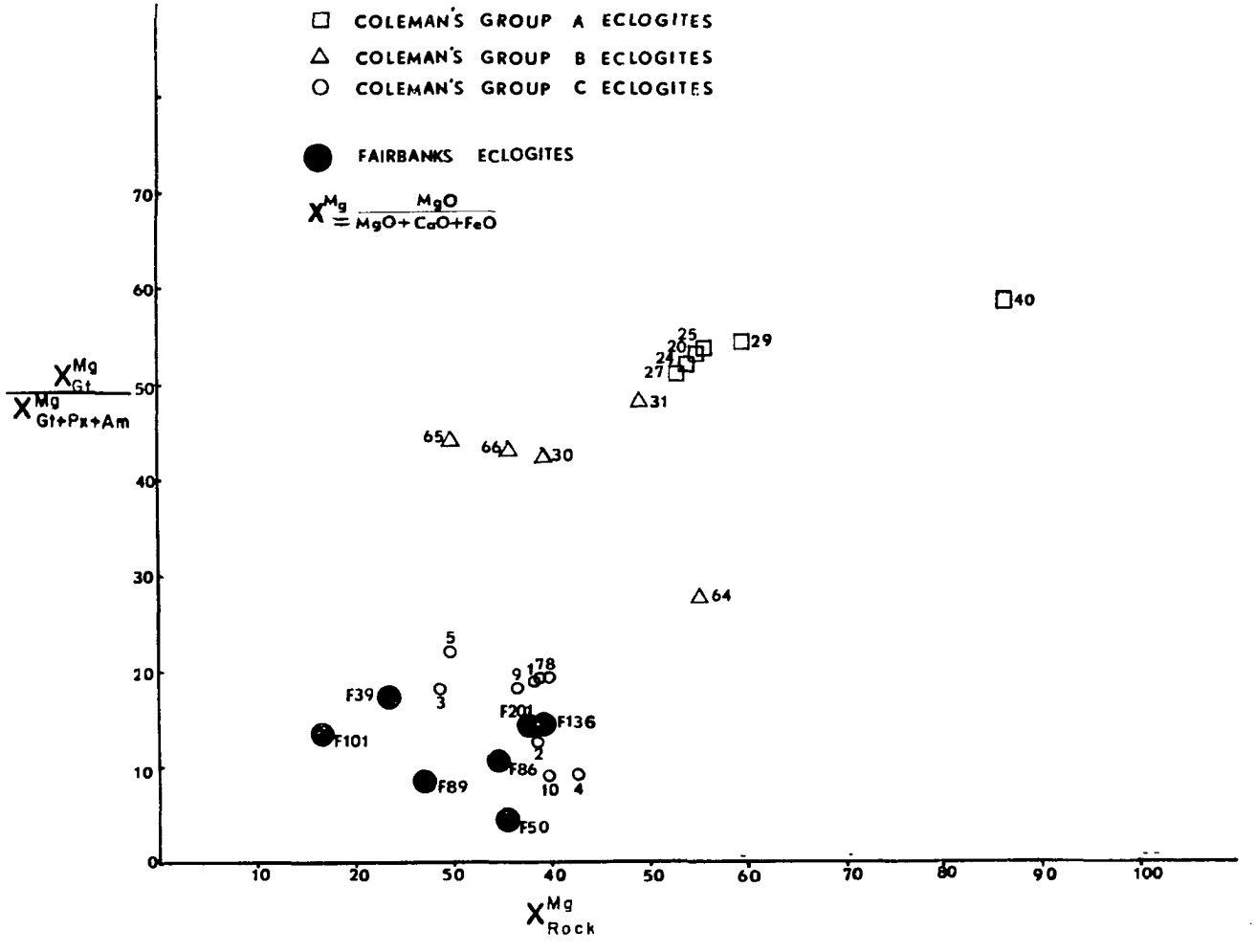


Fig. 35. Variation of MgO in garnet as a function of MgO in garnet + pyroxene + amphibole, as plotted against whole rock MgO content for the Fairbanks and selected other eclogites.

amphibole respectively. Comparison may then be made between the proportion of MgO in the rock and the proportion of available MgO in the garnet, as in Fig. 35. This method of plotting takes into account the effect of coexistent amphibole and the presence of CaO upon the composition of the garnet, and allows comparison of the garnet with the host rock.

It is again evident from both diagrams that the Fairbank's eclogites are comparable only with eclogites of the group C type, formed at relatively moderate geological conditions.

PETROGENESIS OF THE PELITIC SCHISTS

Parageneses in the pelitic schists of the Fairbank's district are shown in the A.K.F. diagrams, Figs. 35 and 37. The lower grade schists from the south of the suspected bounding-dislocation of the eclogitic terrane are characterized by the presence of chlorite.

Reactions leading to the formation of garnets in the schists appear to involve the breakdown of chlorite, and possible reactions include

1) $3\text{Chlo.} + 1\text{Bi} \rightleftharpoons 1\text{Alm.} + 1\text{Phlog.} + 2Al_2SiO_5 + 7SiO_2 + 13H_2O$

2) $6\text{Chlo.} + 1\text{Musc} + 7\text{Qtz} \rightleftharpoons 3\text{Alm.} + 1\text{Phlog} + Al_2SiO_5 + 24H_2O$

These two may be combined, so that

3) $9\text{Chlor.} + 1\text{Musc} + 7\text{Qtz} + 1\text{Bi} \rightleftharpoons$

$$4\text{Alm.} + 2\text{Phlog.} + 3Al_2SiO_5 + 37H_2O$$

All these reactions produce large quantities of volatiles.

No Al_2SiO_5 polymorph was observed in any rock studied, which indicates that the rock were generally not of the appropriate chemical composition. However, in the case of the schist F10 the lack of Al_2SiO_5 would be ascribed to the fact that the reaction to form garnet has not proceeded far. This

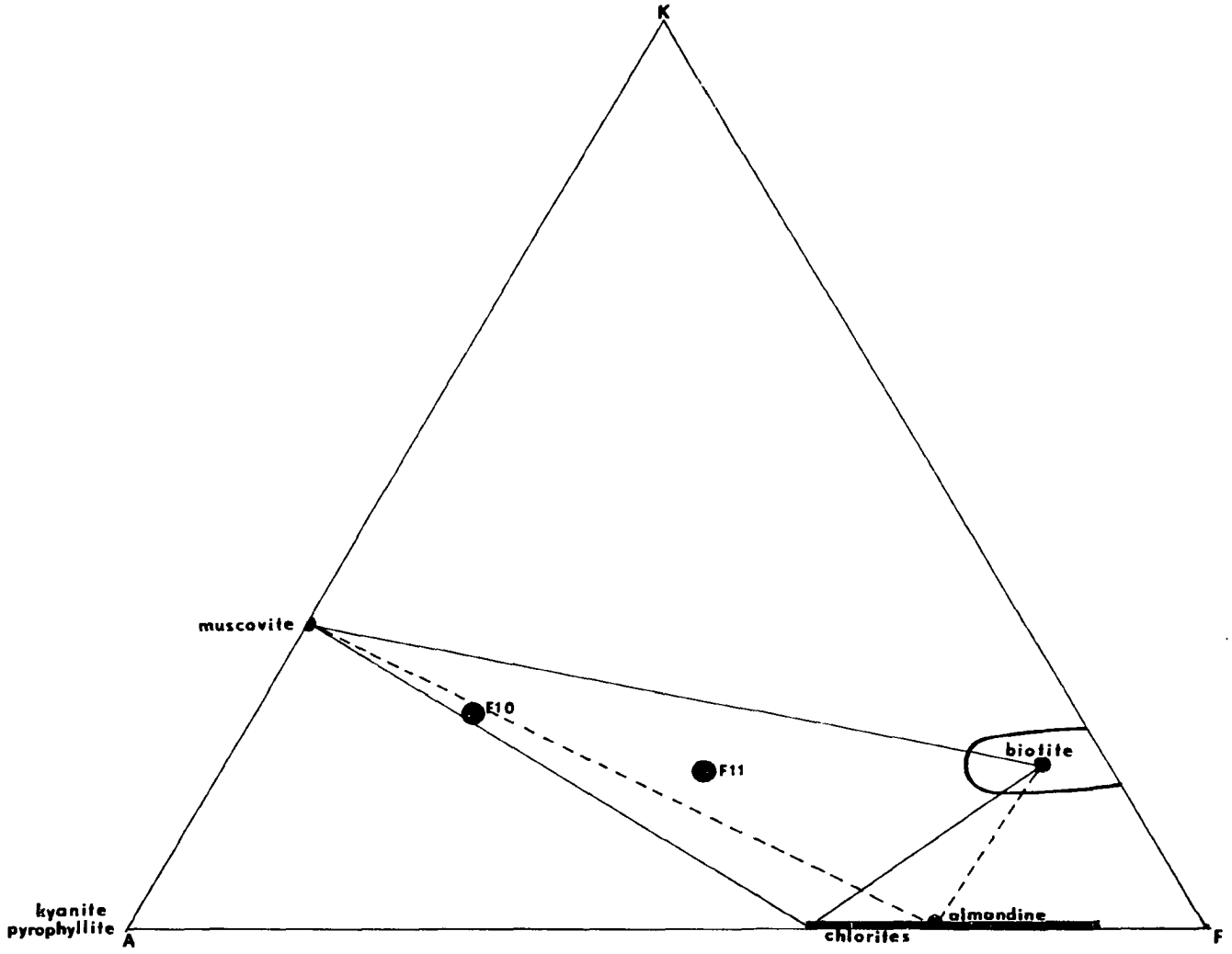


Fig. 36. A'KF diagram for the chlorite-bearing pelitic schists of the study area.

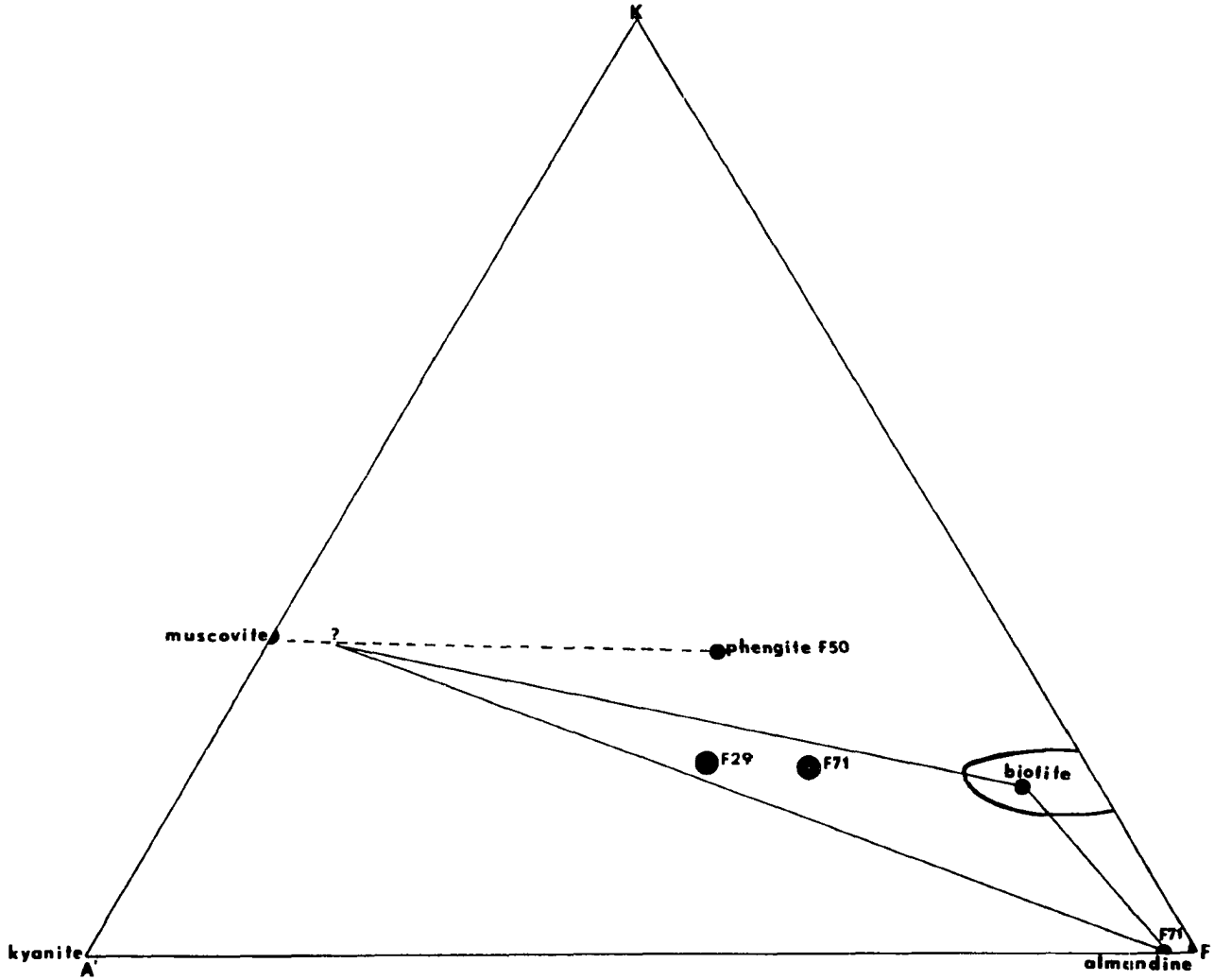


Fig. 37. A'KF diagram for chlorite-free pelitic schists of the study area.

is indicated by the small quantity of garnet and the abundance of the reactants in the reactions 1 - 3.

In the pelitic schists associated with the eclogites in the borrow-pit on the Elliot Highway, the reactions above probably explain the formation of the garnets initially. However, chemical analysis of the garnets from these rocks indicate an appreciable grossular content. The reaction explaining the calcium garnet component could be broken down,

4) $3Al_2SiO_5$ + 4Ct. + 3Qtz. + $H_2O \rightleftharpoons$ 1Clinozoisite + $4CO_2$

5) 2Clzo. + 3 Qtz. + 5Ct. $\rightleftharpoons$ 3Grossular + $5CO_2$ + H_2O.

combining these we have,

6) $6Al_2SiO_5$ + 13Ct. + 9Qtz. + $2H_2O \rightleftharpoons$ 3Grossular + $13CO_2$ + H_2O.

In a carbonate-rich environment the reactions #3 and #6 may be combined to give an almandine-grossular garnet:-

7) 18Chlor. + 2Bi. + 2Musc. + 13Ct. + 2Qtz. $\rightleftharpoons$

11Gt. ($Gro._{27}$, $Alm._{73}$) + 2Phlog. + $73H_2O$ + $13CO_2$

As in the lower grade schists, large volumes of the fluid phases are produced concommitant with the formation of the garnet. The quantity of gaseous products is difficult to reconcile with the concept of a closed system, yet the presence of both the reactants and the products of the reactions in some rocks suggest that this may have been the case. Thermodynamic treatment of the reaction #7 was not attempted, since neither the chemistry nor thermodynamic data are available for several of the minerals and the state of the system is unknown or variable.

Lower pressure limits for the observed parageneses in the pelitic schists, as defined by the lower stability of garnet (Ringwood and Green, 1966) are shown in Fig. 43. Upper pressure limits are difficult to define, but the equilibrium curve for the reaction

Petrogenetic grid for the pelitic rocks.

Reaction:-

6 Chlor. + 1 Musc. + 7 Quartz $\rightleftharpoons$

3 Almandine + 1 Bi. + Al_2SiO_5 + 24 H_2O.

Hirschberg, (in Winkler, 1965.)

Reaction:-

Muscovite $\rightleftharpoons$ Sanidine + H_2O Evans, (1965).

Reaction:-

Cordierite $\rightleftharpoons$ Almandine a) Hirschberg, (op.cit.)

b) Extrapolation from Ringwood and Green, (1966)

Reaction:-

Albite $\rightleftharpoons$ Jadeite + Quartz. Robertson et.al. (1960).

Beginning of melting of granite, after Winkler, (1965).

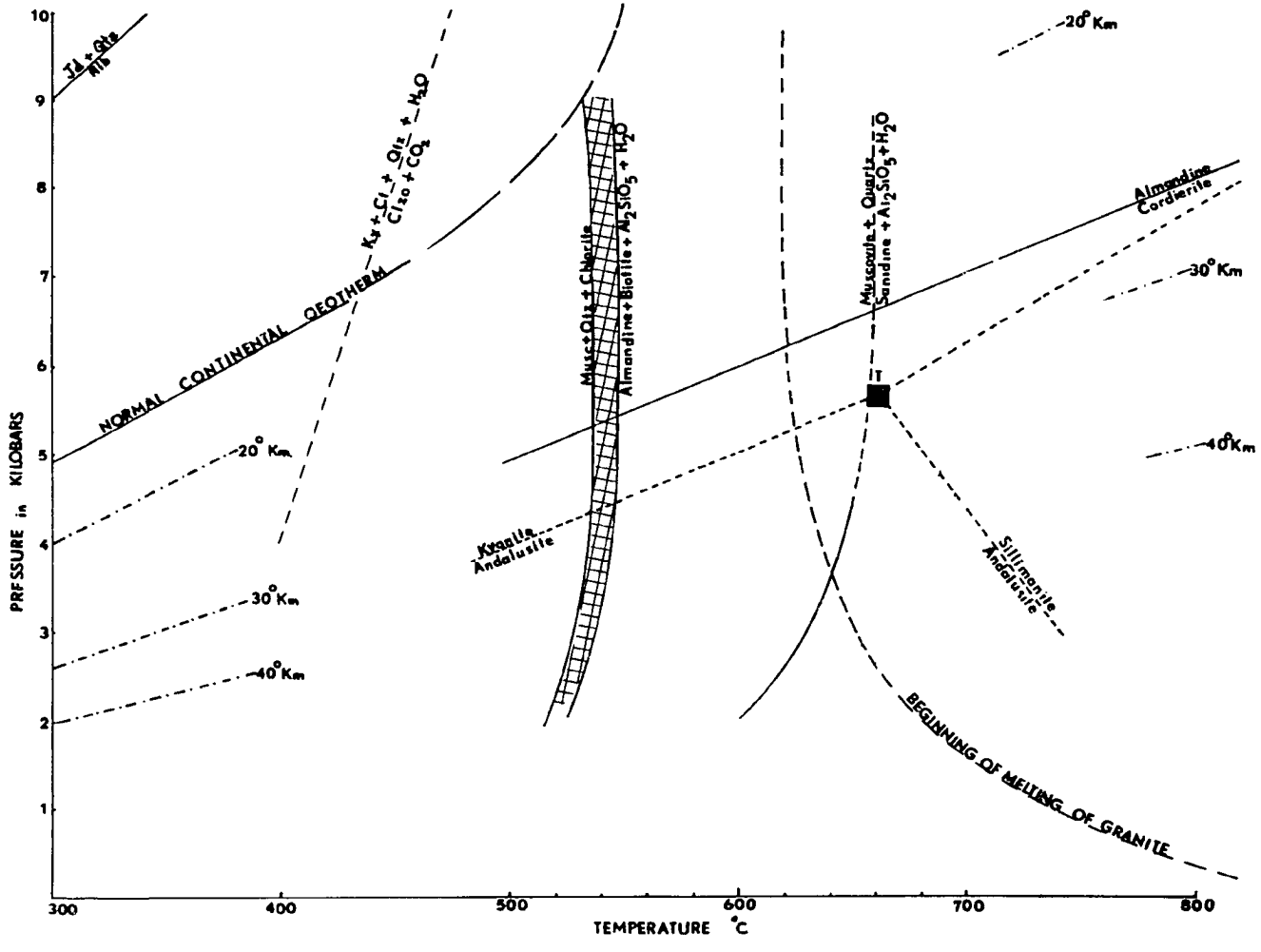


Fig. 43. Petrogenetic grid for pelitic schists of the Fairbanks region.

$$\text{Albite} \rightleftharpoons \text{Jadeite} + \text{Quartz}$$

has definitely not been crossed.

Temperatures of the lower-grade schists must be approximately those of the equilibrium curve for the reaction #2 producing garnet from chlorite, muscovite and quartz, since both reactants and products are present in rocks F10 and F11. The reaction would not go to completion were the system closed to the hydrous phases. Suggested P/T conditions for the lower-grade schist are compatible with the upper part of the greenschist facies, at temperatures of 540 + 20 degrees centigrade at pressures between 5.5 and 15 kilobars.

To test the validity of the proposed reaction 4 in this temperature range, an approximate thermodynamic treatment was applied.

Thermodynamic data for clinozoisite were obtained from Holdaway, (1964), and for the other minerals, where kyanite was taken to be the stable Al_2SiO_5 polymorph, from Robie et al. (1968).

$\Delta G^{\text{reaction}}_{900^\circ K}$, where ΔG is the Gibbs free energy, was derived from the equation

$$\Delta G^{\text{reaction}}_{900} = (2\Delta G^{\text{clzo}} + 4\Delta G^{CO_2}) - (3\Delta G^{ky} + 4\Delta G^{ct} + 3\Delta G^{qtz} + \Delta G^{H_2O}).$$

The values for the molar volume and entropy of the reaction at 900°K were similarly derived. At 900°K the free energy of the reaction is -51.65 Kcal/mol., the entropy is 81.47 e.u. and the decrease in volume is 41.5 cc/mol.

Considering the system as closed, the gases to behave ideally, $P_{fluid} = P_{load}$ and ignoring the compressibility of the solids,

$$\Delta G^{P}_{T} = 0 = \Delta G^{0}_{T} + \int_{P_o}^{P} v.dp \text{ at equilibrium.}$$

and where T is the temperature in degrees K, n is the change in the number of moles of gas and R is the gas constant, the above equation may be written as $\Delta G_T^P = 0 = -51{,}560 + 2.30 \times R \times T \times n \times \text{Log } P$, and therefore Log P at 900°K = 4.161, and the equilibrium pressure for the reaction $3Ky + 4Ct + 3Qtz + H_2O \rightleftharpoons 2Clzo + 4CO_2$ is 20.68 Kilobars.

At this temperature and pressure the slope of the equilibrium curve, $\frac{dP}{dT}$, is given by $\Delta S/\Delta V$, and is equal to 8,2 Kilobars/100 degrees K/mole.

Extrapolation of this curve, shown in Fig. 43, indicates that the products are likely to be stable throughout the range of temperatures considered for the upper greenschist facies.

PETROGENESIS OF THE CALC-MAGNESIAN ROCKS

Paragenetic relations of the Fairbank's eclogites are shown in the A.C.F. projections, Fig. 39 to 41. Only the parageneses of the chemically analyzed rocks are shown. Two distinct parageneses exist for each of the major groups of variants. A zone defined by the intersecting tie-lines of the two groups, Fig. 42, differentiates between rocks with modal calcite which lie to the CaO-rich side of the plane and those with modal plagioclase or clinozoisite.

Clinopyroxenes are omphacites or aluminous diosides in both the calcite-normative and the calcite-free rocks, and they plot close to the composition of the ideal diopside molecule. The lack of the A component is due in part to the high Na_2O-content, which has been seen to be covariant with the Na_2O content of the host-rock. These clinopyroxenes are never so aluminous as those described by Lovering and White, (1968), but are in every respect comparable with those from group C eclogites as defined by Coleman et al. (1965).

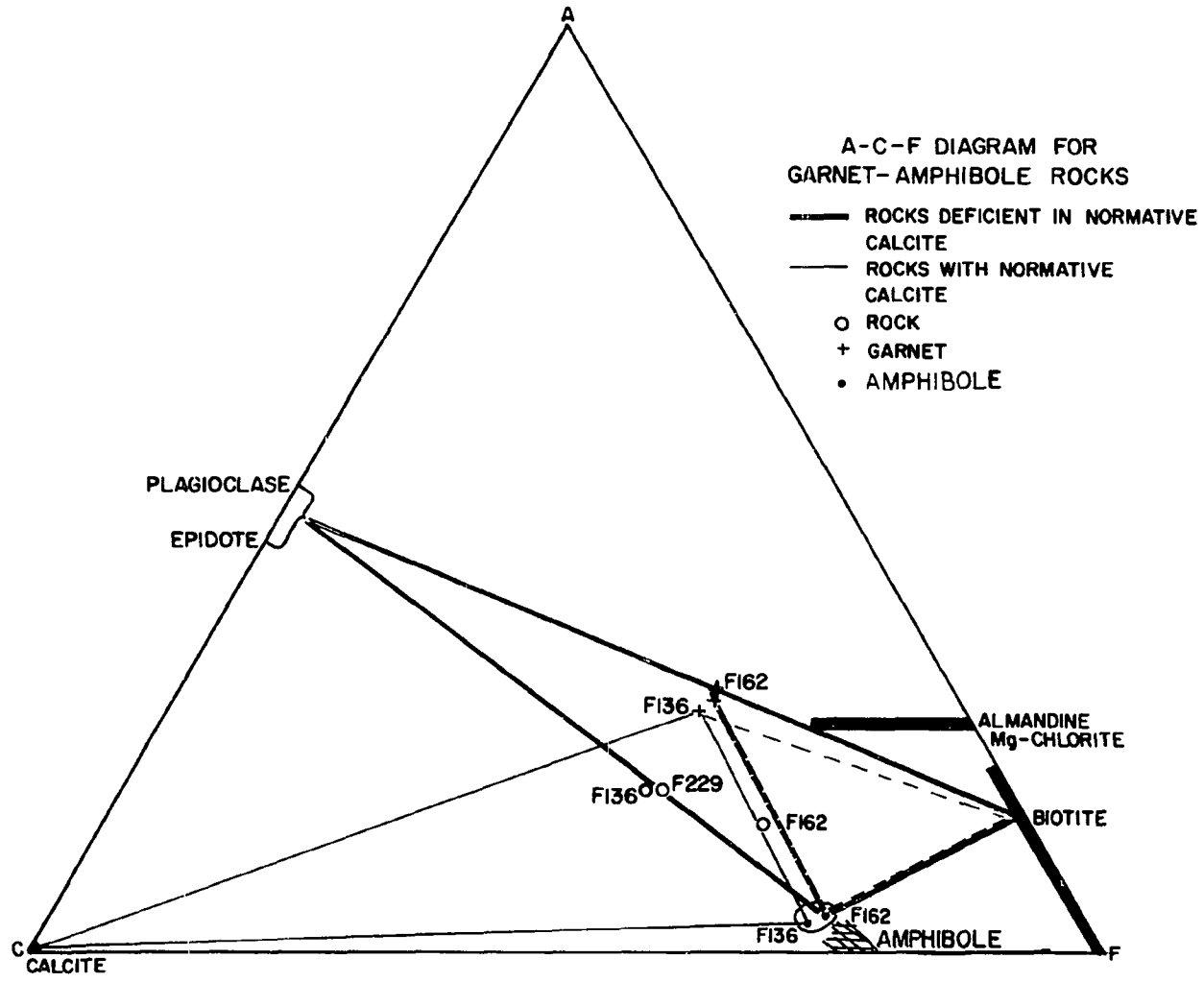


Fig. 38. ACF diagram for the garnet-amphibole (± calcite, quartz, "epidote", plagioclase) rocks of the eclogite-bearing terrane.

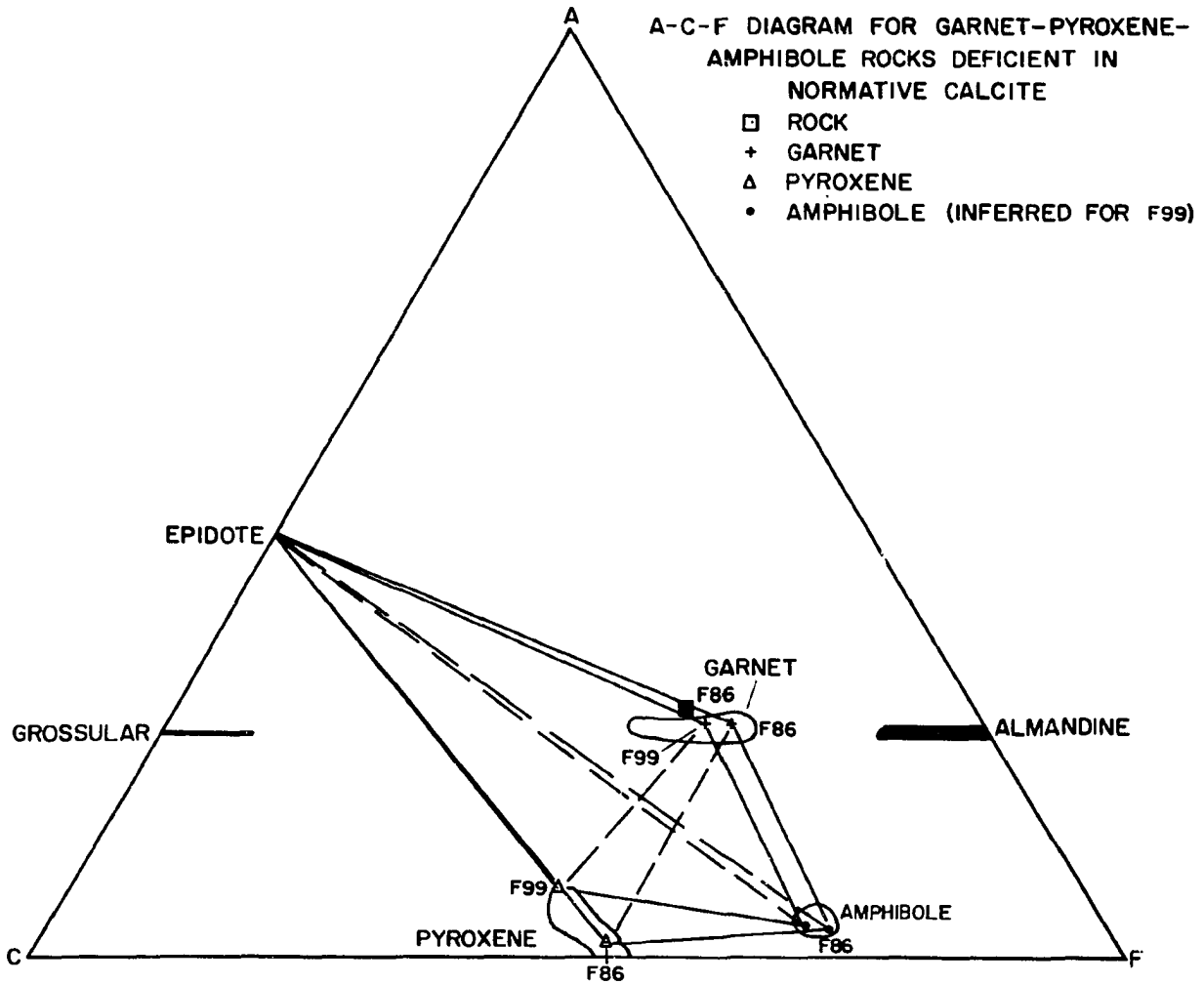


Fig. 39. ACF diagram for garnet-amphibole-clinopyroxene (± quartz, "epidote" plagioclase) rocks without normative calcite.

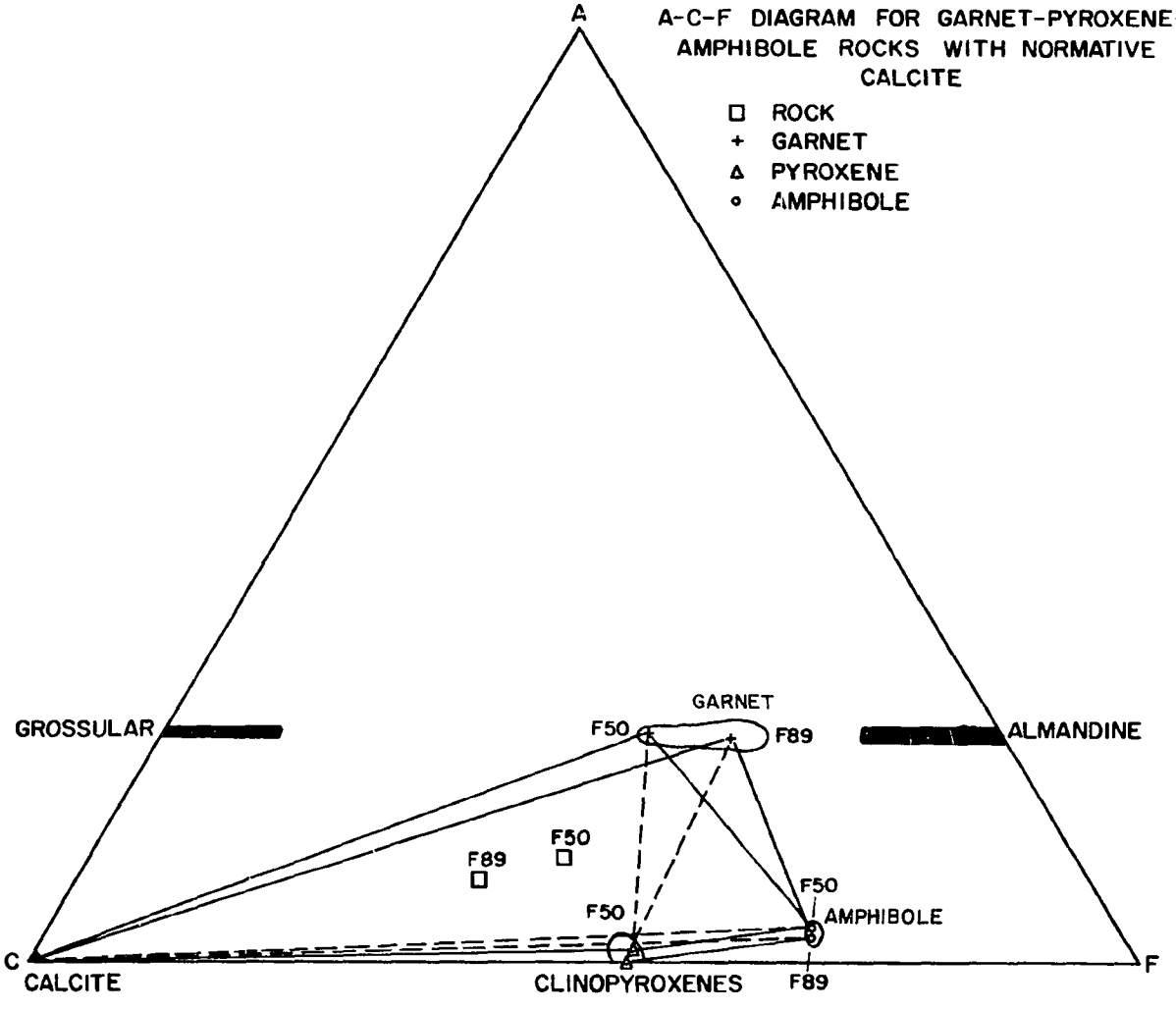


Fig. 40. ACF diagram for calcite normative garnet-amphibole-clinopyroxene (± calcite, quartz, "epidote", plagioclase) rocks from the Fairbanks area.

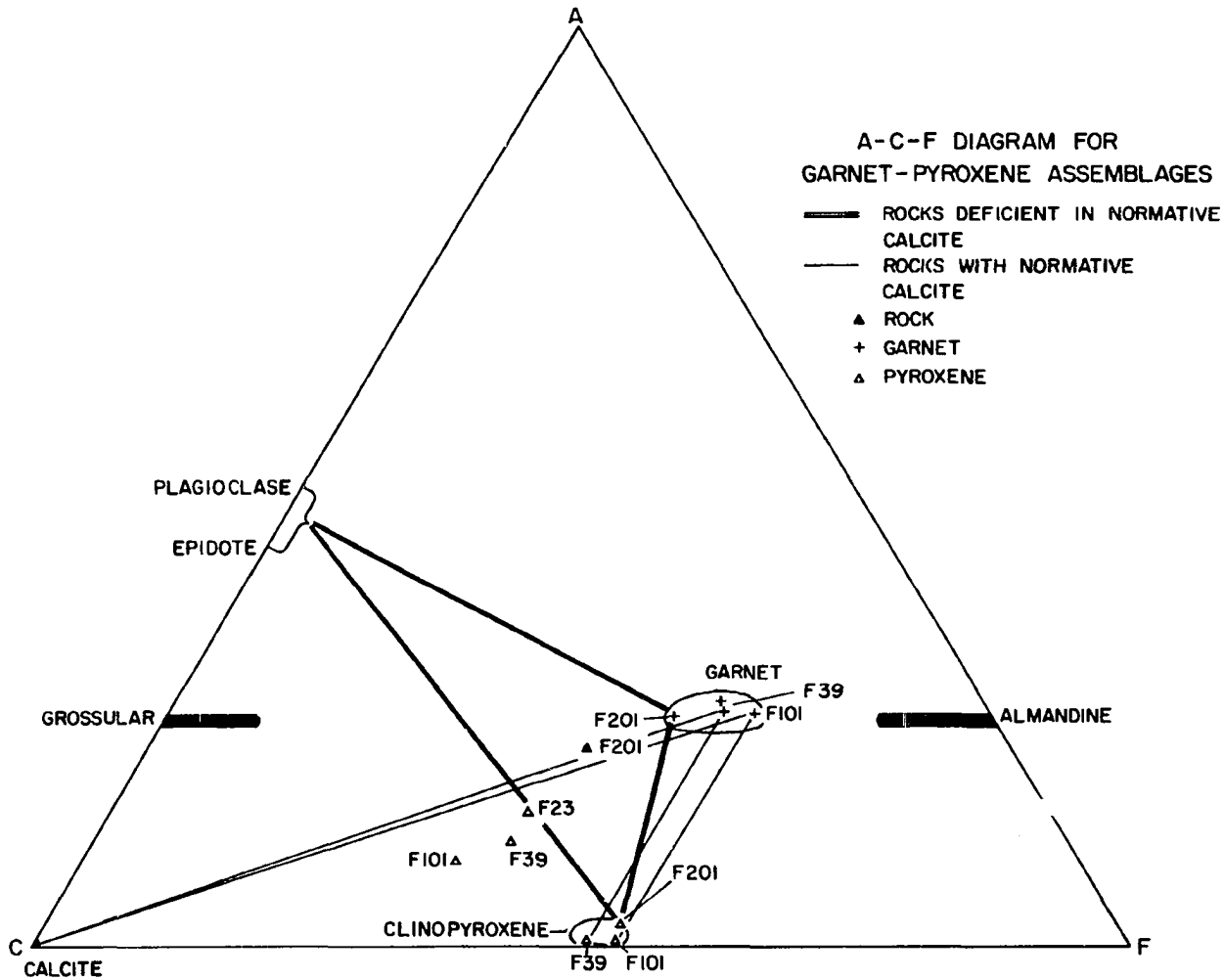


Fig. 41. ACF diagram for garnet-clinopyroxene (± calcite, quarta, "epidote" plagioclase) rocks in the study area.

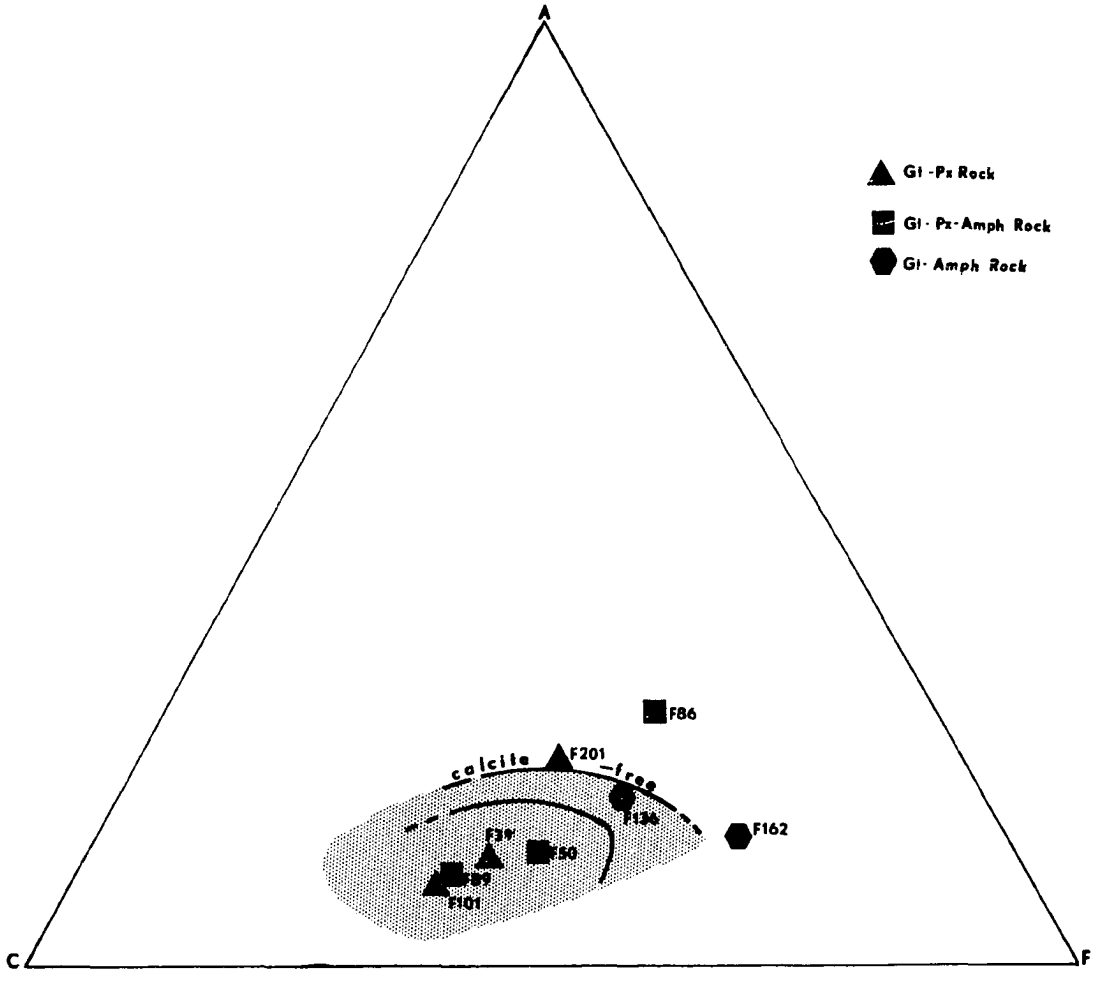


Fig. 42. ACF diagram differentiating calcite-bearing and calcite-free eclogitic rocks in the study area.

Garnets from the Fairbank's eclogites are essentially mixtures of almandine and grossular with minor pyrope in both the calcite-free and the calcite groups. The more calcic rocks tend to have the more grossular-rich garnets, but the proportion of the grossular component never approaches that of the grosspydite garnets reported by Sobolev et al. (1960), $(Gr._{63}py._{18}Alm._{17})$.

Analyzed amphiboles have a restricted compositional range. There is no great difference between those from calcite-free and calcite-normative variants. Though not analyzed, the amphiboles F99 and F162 are plotted on the basis of analoguous optical properties with the analyzed minerals for comparative purposes.

Plagioclase is invariably albite-oligoclase, and the associated epidote-group mineral is clinozoisite or zoisite in the more calcic rocks, and epidote in the more siliceous varieties.

A series of reactions can be postulated for the calc-magnesian rocks in the Fairbanks area which have as their basis the reactions producing diopside from tremolite; production of grossular garnet from clinozoisite and the formation of omphacite from diopside.

Glaucophane, edenite and tremolite have upper thermal stabilities which are very similar. The thermal stability is lowered considerably upon the substitution of iron for magnesium, (Ernst 1966). Lack of data for calcic-amphiboles in the compositional range of the maphiboles reported here leads us to use experimental data on pure tremolite. The considerable iron content of these calcic-amphiboles suggests that the equilibrium curves will possibly be found at lower temperatures.

Petrogenetic grid for the calc-magnesian rocks.

Reaction:-

Tremolite + 3Ct + 2Qtz $\rightleftharpoons$

5Diopside + $3CO_2$ + H_2O Metz et.al. (1964)

Reaction:-

Diopside + Albite $\rightleftharpoons$ Omphacite + Quartz Kushiro, (1965).

Reaction:-

Calcite + Quartz $\rightleftharpoons$ Wollastonite + CO_2 Danielsson, (1950).

Reaction:-

3Woll. + 2 Epidote, (or 5Ct. + 2 Qtz. + 2 Epi.) $\rightleftharpoons$

3 Grossular-andradite + $3CO_2$ + H_2O Chatterjee (1967)

Reaction:-

Albite $\rightleftharpoons$ Jadeite + Quartz Robertson et.al. (1960).

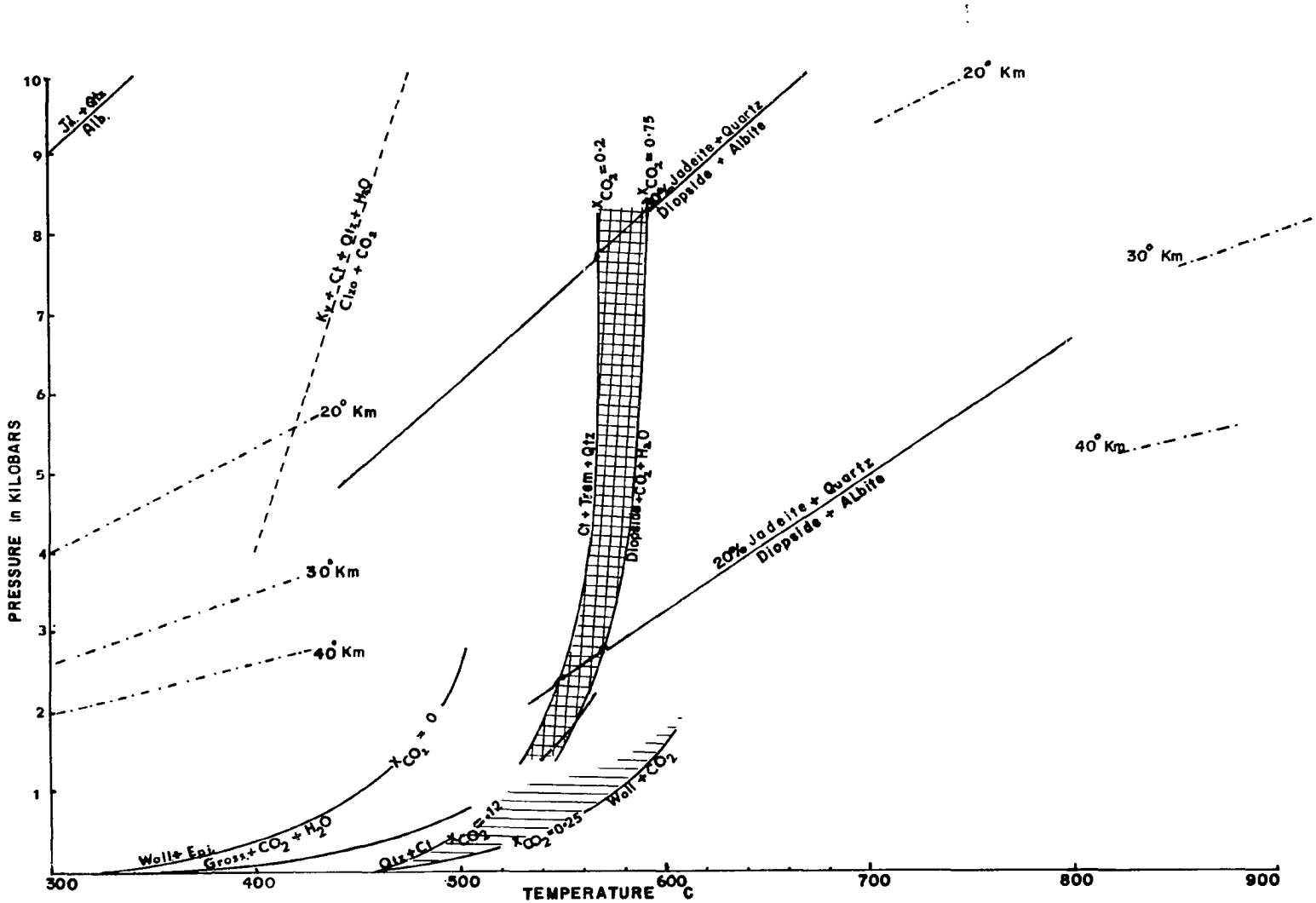


Fig. 44. Petrogenetic grid for the eclogitic rocks of the study area.

Metz et al. (1964) studied the reaction

8) Tremolite + 3Ct. + 2Qtz $\rightleftharpoons$ 5 Diopside + 3 CO_2 + H_2O, and his curves for the reaction at mole fractions of CO_2 = 0.2 and 0.75 are given in Fig. 44. It should be noted that below the lower value, the curve is strongly influenced by X_{CO_2}.

Kushiro, (1965) studied the reaction

9) Diopside + Albite $\rightleftharpoons$ Omphacite + Quartz.

Bell and Kalb (1965) find that the equilibrium curves are essentially the same whether the reaction occurs in a silica-saturated or silica-undersaturated environment. The curve for the formation of omphacite with 20% of the jadeite component was checked thermodynamically using the data of Bell and Davis, (1969). The upper stability of albite given by Kushiro (1965) agrees well with the equilibrium curve for the reaction

10) Albite $\rightleftharpoons$ Jadeite + Quartz, as calculated by Hlabse and Kleppa (1969)

Chatterjee, (1967) gives the equilibrium curve for the reaction

11) Epidote + 5Ct. + 3 Qtz. $\rightleftharpoons$ 3 Gross-and. + 5 CO_2 + H_2O. His curve is plotted in Fig. 44 and is below a value of X_{CO_2} = 0.13, very temperature sensitive to the mole fraction of CO_2.

The reaction producing wollastonite from calcite and quartz also involves decarbonation, and as no wollastonite was seen in any of the calcite and quartz-bearing rocks, an estimate of the X_{CO_2} may be made. Danielsson's (1950) curves for the above reaction plotted on Fig. 44 suggest that at 600 degrees and about 6 kilobars, (the P/T conditions suggested by the associated gneisses), X_{CO_2} in the eclogitic rocks must have been @ 0.2 to inhibit the formation of wollastonite.

The amphibole and coexistent clinopyroxene in rock F50 are almost isochemical, as noted in section on variation diagrams. This suggests

Table 6. Comparative structural formulae of coexistent amphiboles and pyroxenes recalculated on the basis of 24 oxygen atoms per formula unit.

	F50		F86		F89		F136
	CPx	Am	CPx	Am	CPx	Am	Am
Si	7.88	7.67	7.96	7.997	7.88	7.70	7.821
Al	0.64	0.96	1.16	0.907	1.16	1.014	1.060
Ti	0.12	0.057	0.04	0.025	0.08	0.023	0.027
Total Fe	0.68	1.062	0.96	1.233	1.04	1.367	1.260
Fe	0.08	0.066	0.24	0.194	0.24	0.176	0.191
Fe	0.6	0.996	0.72	1.039	0.80	1.191	1.069
Mn		0.005		0.05		0.021	0.05
Mg	3.08	3.754	1.96	2.623	2.2	3.379	3.642
Na	0.44	0.438	1.36	0.518	1.32	0.501	0.493
Ca	3.12	2.011	2.52	1.325	2.52	1.918	1.641
K		0.054		0.089		0.033	0.090

that reactions #8 and #9 may be combined. Adjusted to the known chemistry:-

12) 12 Ca-Amph. + 14 Ct. $\rightleftharpoons$ 30 (10%) Omph. + 1Clzo.+ 17 Qtz. + 18 MgO
+ 12 FeO + 7 Sphene + 14 CO_2 + 12 H_2O

In this same rock, F50, the core of the garnet is poikiloblastic, with inclusions of quartz, cacite and clinozoisite, suggesting that the production of the early reaction was as reaction #11, only with epidote replaced by clinozoisite. Adjustment of the stoichiometry of the reaction #11 to accommodate the MgO and the FeO produced in reaction #12, gives

13) 2 Clzo. + 16 Ct. + 6 Sio_2 + 18 MgO + 12 FeO $\rightleftharpoons$
$6Gt(Gr_{50}\ Py_{20}\ Alm_{30})$ + 16 CO_2 + $2H_2O$.

Thus the eclogite paragenesis in rock F50 could be produced by a combination of these reactions #12 and #13 thus:-

14) 12 Ca-Amph. + 30 Ct. + 1 Clinozoisite $\rightleftharpoons$
30(10%) Omph.+ 6Gt.($Gr_{50}Py_{20}Alm_{30}$) + 11 Qtz.+ 7 Sph.+ 30 CO_2 + 14 H_2O

Quartz is a product of the reaction, and lack of quartz can not be a constraint. In this particular reaction, however, CALCITE IS AN ESSENTIAL REACTANT.

The foregoing discussion concerned only the rock F50. It is more generally applicable to the Fairbanks eclogites to say that CaO, rather than calcite, is an essential reactant. Thus in the rocks deficient in normative calcite, but rich in normative anorthite, as all are, the CaO may well be derived from the epidote-group minerals.

In a calcite-free rock, F 86, the reaction #14 changes to:-

15) 4 ca-Amph. + 2 Alb + 1 Clzo. + nSio_2 $\rightleftharpoons$
6(30%) Omph. + 4 Garnet. + nTalc + nH_2O.

Knowledge of the exact composition of the garnet formed by this reaction, rather than the overall composition, would allow the replacement of the "n" values by integers.

Thus in the case of calcite-free rocks, one of the more important differences is that pCO_2 has no effect. In view of the fact that both reactants and products are observed in the parageneses of calcite-free rocks, the partial pressure of H_2O probably provides the most serious constraint to the forward reaction.

For calcite-bearing rocks, the reactions #12, 13, 14 produce large amounts of fluid phases, any or all of which could inhibit the forward reaction in a closed system.

Thermodynamic calculation of the equilibrium curves for reactions #14 and #15 cannot be made because of the lack of data. All that may be said is that open systems and low mole fractions of CO_2 would favour the reactions.

Parageneses consisting of products alone, reactants alone and both products and reactants together in many of the reactions discussed demands explanation. This is especially true since the physical variables, temperature and pressure, of metamorphism must have been essentially the same over the restricted area from which the analyzed rocks were collected.

Insufficient supply of any reactant would obviously limit the extent of the reactions. However, with reference to the reaction #8 forming diopside and gaseous products from tremolite, calcite and quartz another explanation may be postulated. For a fixed temperature and pressure within the limiting equilibrium curves for the reaction, (X_{CO2} = 0.2 and 0.75) the ultimate extent of the forward reaction is strongly governed by the mole fraction of CO_2.

Miyashiro, (1963), notes that because of the reaction:-

16) $C + O_2 \rightleftharpoons CO_2$

the presence of graphite may, by increasing the apparent mobility of oxygen, control the progressive metamorphic process. Since most of the proposed

reactions leading to the parageneses in the eclogitic rocks discussed in this paper also evolve CO_2, these reactions cannot be independent of reaction #16 nor of the partial pressure of CO_2.

It is therefore highly significant that carbonaceous material is abundant in the garnet-amphibole assemblages, but almost entirely absent in the garnet-omphacite assemblages of this study. High partial pressures of CO_2 favour both the presence of carbonaceous material (reaction #16) and the garnet-amphibole assemblage (by analogy with reaction #8).

Estamated total pressures for the reaction producing omphacite from diopside indicate pressure variations from 3 to 10 Kilobars, (Kushiro, 1965). Lower pressure estimates based on the stability of almandine garnet in the temperature range indicated by the pelitic schists are between 5.5 and 6.5 Kilobars.

Taking 28% jadeite in the omphacite as an average value for those of the Fairbanks omphacites not limited by lack of reactants, pressure estimates are between 5.5 and 7.5 Kilobars for the temperature range 550 to 600 degrees centigrade.

Temperature estimates for the above pressures of metamorphism of the calc-magnesian rocks can be made by analogy with the reaction #8 for production of diopside from tremolite. A range of only 30 degrees is indicated, from 560 degrees at 5.25 Kilobars and X_{CO_2} = 0.2 to 590° at 7.25 Kilobars and X_{CO_2} = 0.75. Estimates of temperature based on reaction #11 forming grossular from epidote at the above pressures suggest that above X_{CO_2} = 0.12, the temperature is close to 570 degrees.

To summarize, the temperature of formation of the eclogitic assemblages appears to be between @560 to @590 degrees at pressures ranging from 5.75 Kb. to 7.25 Kb. Mole fractions of CO_2 are in excess of Ca.0.2, and

may locally be as high as 0.75. The presence of carbonaceous matter favours high X_{CO_2}, and for a temperature of 580 degrees at 6.25 Kb. total pressure all the observed variants could exist at appropriate mole fractions of CO_2. The presence of carbonaceous matter in the garnet-amphibolites suggests that this is the case.

These P/T conditions are highly compatible with the evidence derived from a study of the associated pelitic schist parageneses. The pressure is compatible with that derived for the schists to the south of the suspected dislocation bounding the eclogite terrane, but the temperature of the chlorite-bearing schists must be 40±10 degrees lower.

GEOCHRONOLOGY

Discordant age dates from polymetamorphic basement complexes are to be expected, for, as pointed out by Evernden, (1960) quantitative retention of argon is expected only below 300 degrees centigrade. The argon retention is also dependent upon the type of mineral and the degree of recrystalization. Amphibole, biotite and muscovite are increasingly susceptible to isotope loss, according to Moorbath (1960).

Data for the age dates derived from the eclogite-bearing terrane and adjacent areas are given in Table 7. The oldest date, 470 ± 35 M.Y., is of an amphibole from a dense fresh garnet-clinopyroxene-amphibole rock collected at the same locality as most of the analyzed rocks. Due to difficulties in analyzing the low-potassium content the true age may be considerably older. This date probably represents the stabilization of the eclogitic rocks after the tectonic episode which produced the recumbent isoclines with the north-westerly trending axes.

An amphibolite from the lower grade sequence at Fox, six miles south of the study area, gave a date of 240±18 M.Y. Whole rock and muscovite dates from Fox and from Cleary Creeks gave K^{40}/Ar^{40} dates of around 165 M.Y. (Forbes et al. 1968). In view of the superior argon-retention of amphibole, it is possible that these dates also relate to late Permian tectonic episode.

Much younger dates were recorded from a biotite-bearing garnet-amphibolite in the borrow-pit on the Elliot Highway very close to the site of the oldest date. Amphibole, biotite and muscovite from this garnet-amphibolite gave K^{40}/Ar^{40} dates of 132±8.8, 108.5±3.4 and 103.5 ±3.4 M.Y. respectively. Convergence of these dates with the age of emplacement

Table 7 K^{40}/Ar^{40} Analytical data

SAMPLE NUMBER	ROCK TYPE	ANALYSED MINERAL	%K	Radiogenic Ar^{40}(p.p.m)	% Radiogenic Argon	AGE AND ESTIMATED ERROR
F49	Gt-Px-Am-Ct-Qz	Amphibole	0.166	0.00630	64.25	470 ± 35 M. Y.
F229	Amphibolite	Amphibole	0.514	0.00940	66.80	240 ± 18 M. Y.
F136	Garnet-Amphibolite	Amphibole	0.412	0.00404	41.95	132 ± 8.8 M. Y.
F71	Pelitic Schist	Muscovite	6.810	0.05790	80.10	115 ± 2.6 M. Y.
F136	Garnet-Amphibolite	Biotite	6.842	0.05440	76.20	108.5 ± 3.4 M. Y.
F136	Garnet-Amphibolite	Muscovite	4.970	0.03770	40.45	103.5 ± 3.4 M. Y.
Pedro #1	Quartz-Diorite	Amphibole	0.822	0.00546	56.85	90.7 ± 5.1 M. Y.

Analyses. GEOCHRON LABS. INC.

of the Pedro Dome plutons to the east is significant. Coarse muscovite from pelitic schist F71 from the borrow-pit gave a data of 115 ± 2.6 M.Y., and is apparently associated with the early Cretaceous tectonic episode which produced the garnet-amphibolite. Thus some of the garnet-amphibolites appear to be retrograded eclogites, probably formed during an early Cretaceous metamorphic episode which activated the folding formed during an early Ordovician episode. An late Permian tectonism probably initiated the folding on a northeasterly axis which localized intrusions in the early Cretaceous episode.

CONCLUSIONS

1). Whole rock chemistry and field relations strongly suggest that the eclogitic rocks of the Fairbanks area are metasediments.

2). The calcite bearing eclogites represent a newly described compositional variant among eclogitic rocks.

3). Chemical mineralogy of the garnets and clinopyroxenes from the Fairbanks eclogites show that these rocks are true eclogites.

4). Variation diagrams, distribution coefficients and chemistry of the coexistent garnets and pyroxenes characterize the rocks as typical group C type eclogites of blueschist terrane.

5). Pelitic schists in the area to the south of the eclogitic terrane were crystallized at temperatures between 520 and 560 degrees at pressures in excess of 5.5 kilobars. They may have been retrograded by an early Cretaceous metamorphic pulse.

6). Pelitic schists intimately associated with the eclogitic rocks were crystallized at temperatures between 550 and 620 degrees, at pressures in excess of 5.5 Kb.

7). With the addition of CaO and Na_2O the analyzed amphiboles are almost isochemical with the coexistent omphacites, and both have Na_2O contents which are interdependent with the whole rock Na_2O content.

8). CaO is an essential reactant in the production of garnet in the eclogitic rocks of this study.

9). The coexistence of both products and reactants of several reactions leading to the eclogite assemblages suggests that reactions may have been inhibited by the abundant production of gaseous products.

10). CO_2 is the most abundant of the possible gaseous products and variations of the mole fraction of CO_2 could produce the observed mineralogical assemblages at a single temperature and pressure.

11). Some of the garnet-amphibole rocks may represent retrograded eclogitic assemblages in an early Cretaceous metamorphic event.

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APPENDIX 1.

Estimated modal analyses of rocks in the Fairbanks area.

1) Mica quartzites.

2) Pelitic schists.

3) Garnet-amphibole rocks.

4) Garnet-amphibole-pyroxene rocks.

5) Garnet-pyroxene rocks.

ROCK NUMBER	GARNET	PYROXENE	AMPHIBOLE	QUARTZ	CALCITE	PLAGIOCLASE	MUSCOVITE	BIOTITE	CHLORITE	PHLOGOPITE	"EPIDOTE"	APATITE	SPHENE	RUTILE	OPAQUES	OTHER
F8	3			80		10	5	X	2					X	X	
F9	5			75		10	5	2	3					X	X	
F140	X			70		10	10		5					X	5	X
F144				80			5	X							X	
F173				80			X							X		X
F180				70	5		10						X		10	X
F130	X			90			5	X					X	X	X	X
F114	10			75			10							X	X	
F117	2			70			5	2	4		X			X	5	
F118	2			85			5		5					X	X	
F123	2			65			10		10			X	X	X	X	
F124	5			70			5	3	2					X	X	
F126	5			70			10	2	3					X	3	X
F190	10			70			10							X	5	
F191	10			80	X		5							X	10	X
F172				75			15								7	
F177	X			70		3	20	X	X							X

ROCK NUMBER	GARNET	PYROXENE	AMPHIBOLE	QUARTZ	CALCITE	PLAGIOCLASE	MUSCOVITE	BIOTITE	CHLORITE	PHLOGOPITE	"EPIDOTE"	APATITE	SPHENE	RUTILE	OPAQUES	OTHER
F10				30		5	40	5	5						5	Tm
F11	2			30		5	10	10	20				5		x	Tm
F133	2			35		10	15		25		x		x		5	
F134	10			50			10		10						5	
F142	4			60		15	10	x	5					x	5	
F12	2			50		15	10	10	10			x			x	Tm
F13	x			40		20	10	10	15		x		x		x	Tm
F174				40		5	40	x	x						5	Graph
F175	5			40		20	20									
F176				40			20									Graph
F178	5			60		5	20									
F29				15		10	40						10	5	5	
F70	20			35			10					2		5	2	Tm
F71	10			20		5	50	2			2	x		2	x	Tm
F107				50		10	20						2		x	Graph
F108				30			20							2	5	Graph
F109	15			10		15	10		20				x	x	x	
F112	10			40		15	20		10					x	x	
F113	10			40			40							x	x	
F115	20			5			70		x					x	x	
F119	5			x			85		5				x	x	5	Graph
F120	5			60		10	15		10		x				x	Graph
F122	10			45		20	10						x	x	x	
F125	10			60		20	5		x							
F131	2			60			5							x	x	Graph

ROCK NUMBER	GARNET	PYROXENE	AMPHIBOLE	QUARTZ	CALCITE	PLAGIOCLASE	MUSCOVITE	BIOTITE	CHLORITE	PHLOGOPITE	EPIDOTE	APATITE	SPHENE	RUTILE	OPAQUES	OTHER
F17	20	20		5	30	5	5	2			5	x	5		x	
F18	10	10		5	30	15	5	5	5			x	x			Graph
F25	5	30		5	30	5	5	x	x	x						
F39	30	30			20		x		x			5	5		x	Stilp
F54	40	20			20		10				5	x	5		x	
F160	20	30			30		5					x	5		x	Orth
F14	5	10		70	5						5	x	x		x	
F76	5	15		40			10				10		x		x	Graph
F7	5	20	10		45		5		5		x		2		5	
F15	10	20	5	10	35	x	10		x		x	x	5		x	
F16	20	20	10	5	30	5	5	x			x	x	5		x	
F20	10	20	5	5	15	10	5	5	5		x	x	5		x	
F21	10	30	5		40	5	5				x	x	x		x	
F22	10	25	10	5	15	5	5		5		5	x	5		x	
F24	20	20	5	10	30	x	10			x	x	x	5	x	x	
F45	20	30	10		25			x		x	x	x	x	x	x	Orth
F46	10	15	5		40		5			x		5	5	x		
F48	20	20	10		10	5	5			x	x	x	x		x	
F57	10	20	5		40		5				5	x	5		x	
F59	20	20	5		40	x	5			x		x	5		x	
F73	20	20	5	x	30						5	5	5		x	Orth
F75	10	40	5		20	x	x			x	10	x	5		x	Orth
F78	10	25	5		40	x			x			x	5	x	x	Orth
F80	10	50	5	x	10						5	x	5		x	
F82	15	30	5		20						5		2		3	Orth
F83	15	30	10	10	20	x				x		5	5		x	Orth
F85	30	40	5		20							x	x		x	Orth
F90	25	25	5		20						x	5	10		x	Orth
F92	25	25	5		25					x	x	5	5		x	
F94	30	25	10		20							5	5			
F100	25	30	5		10		5			x	x	5	5		5	
F101	20	40	10	x	10						x	5	5		x	
F127	20	30	5		10		10				5	5	10			
F154	15	15	5	x	40	x	15				x	x	5		x	
F201	10	20	10	25								5		5	x	

ROCK NUMBER	GARNET	PYROXENE	AMPHIBOLE	QUARTZ	CALCITE	PLAGIOCLASE	MUSCOVITE	BIOTITE	CHLORITE	PHLOGOPITE	EPIDOTE	APATITE	SPHENE	RUTILE	OPAQUES	OTHER
F1	20	15	10		20	10	20					x	5		x	
F2	15	15	10	2	30	x	15				x	x	x		x	
F3	25	10	15		30		10	x		x	x	x	x		x	
F4	15	15	15		30		15				5	x	x			
F5	20	15	10	2	30	x	5				x	x	x		x	
F40	20	20	25		15	x	5		x		5	x	x	x	x	
F50	15	15	20	x	30		5				5	x	5		x	
F63	10	10	10		40		5		x	x	x	x	x		x	
F64	15	15	10		40		10			x		x	x		x	
F66	10	10	10	10	40	x	5			x	10	x	5		x	
F74	20	15	15		30		5			x	5	x	x		x	Orth
F93	25	15	15		25							5	5		x	Tm
F105	15	15	10		30		10			x	5	5	5			
F158	15	10	15		20				5			10	5		15	
F196	15	20	15		15	5	10	5				5		x	5	
F200	10	10	10	x	50	5					x	x	x			Graph
F86	20	15	10	30		x					x	x		5	x	Orth
F99	15	5	15	30		10	x				15		x	x	x	
F36	10	10	35		20	10			x		x	x	x		x	
F38	10	10	20		40	10		x	x	x	5	x	5		x	
F42	10	5	15	10	40		10				5		5		x	Orth
F43	30	10	30		15	x	5		x	x	5	x	x		x	
F44	5	x	15		40	10	5	10	10		x	x	x	x	x	
F49	15	10	20		40	5	10				x	x	5		x	
F55	15	5	20		25		10				5	x	x		x	
F56	30	5	10		30		15				x	x	10		x	
F58	10	x	10		x	30	10		20				5	x	x	
F68	10	5	20		50		10				x	x	x	x	x	
F72	20	10	20	x	20	x	15				x	x			x	Tm
F89	20	15	30		10						x	10	5		x	
F148	20	10	25	5	15		10				x	5	5		x	
F194b	20	5	25		35		5				x	5	x		x	
F194c	15	5	35		25	5	10				x	x	x		10	

ROCK NUMBER	GARNET	PYROXENE	AMPHIBOLE	QUARTZ	CALCITE	PLAGIOCLASE	MUSCOVITE	BIOTITE	CHLORITE	PHLOGOPITE	EPIDOTE	APATITE	SPHENE	RUTILE	OPAQUES	OTHER
F6	10		15	10	15	x	25	5		5	5		x	x	x	
F19	5		15		40	10	x	10	x		5		x		x	
F34	20		30		15	10	5	x	x		5		5		x	
F35	20		30	5	20	15			x			x	x		x	
F52	15		35		25		15				x	x	5		x	
F53	20		15		40		10				x	x	5		x	
F61	10		20		30	5			5	5	x		x	x	x	
F104	25		20		30	x	10			5	x	x	x			
F106	10		25		25	5	5	10				5	5			
F135	30		20		10		10	15				x	x	x	x	Tm
F136	10		30		15	5	10	15				x		5	x	Tm
F137	20		15		30		10	5	x		x	5	x	x		
F147	20		20		30	5	5	x			x	x	5		x	
F151	20		15	5	40		10				x		5			Stilp
F153	15		65		10		5					x	x		5	
F156	5		30		x	10	10		20		10	x	x	x	x	
F161	15		25		30			x			5	x	5		x	Pist
F163	20		20	10	30		10				x	x	5			
F164	15		40	x	x	10			5		x	x	x	x	2	Pist
F167	25		25		x	20			10		5	5	x	x	x	
F169	25		30		x	15	x	x			10	5	x		x	Graph
F184a	15		50		5	10	5					x	x	x		
F184b	20		20		20	5	5	15			x	x	x			Graph
F185	15		20		15	10	5	15	x		5	x	x	5		Graph
F186a	20		10		5	30	5	10	10		x	x		x	x	Graph
F186c	20		10		5	30	5	10	10		x	x		x	x	Graph
F187c	20		20		10	25	5	5	5			5	5		x	
F189	10		50		5	5		5	15		x	x	x			Graph
F193	40		15		20	x	10				x	x	5		x	
F194a	25		35		15	5	5	5			x	5	5	x	x	
F195	25		30	5	10	20		5	10		5	10	x		x	
F96a	25		10	35			10		5	10	5			x	x	
F96b	20		10	40			5		x	5	10	x		x		
F97	25		25	40		x	5			x	5		x	x	x	
F111	10		5	30		20	30			x	x			x		Tm
F152	25		20	30			15	x	5	x	5			x		Tm
F187b	20		10	5		20	10	10	15			x		x		Tm
F157	15		40			15	10	5	x		x	x	5	x		
F162	5		60			5	5	x	5		x	x		5	x	
F166	25		10			20		15	15		x			x		Graph
F186b	20		70				5	x						x		Tm
F187a	15		25			20		15	15			x		x		Graph
FecA	20		40			10	15	10				x		x		

APPENDIX 2.

Key to sources of chemical analyses of eclogitic rocks and minerals used in text.

CODE USED IN TEXT	AUTHOR'S SAMPLE NUMBER	REFERENCE	LOCALITY	ROCK OR MINERAL TYPE
1	102-RGC-58	Coleman, R. G., et al 1965	Junction School	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
2	207-RGC-59	"	Valley Ford	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
3	62-RGC-58	"	War Creek	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
4	36-NC-62	"	New Calendonia	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
	"	"	"	Amphibole
5	100-RGC-58	"	Tiburon	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
6	113-RGC-58	"	Occidental	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene

CODE USED IN TEXT	AUTHOR'S SAMPLE NUMBER	REFERENCE	LOCALITY	ROCK OR MINERAL TYPE
7	Ca 1055	Morgan,B.A.,1967 Ph.D Thesis,Princeton	Venezuela	Eclo-Amphibolite
	"	"	"	Garnet
	"	"	"	Pyroxene
	"	"	"	Amphibole
8	Ca 1052-1	"	"	Eclo-Amphibolite
	"	"	"	Garnet
	"	"	"	Pyroxene
	"	"	"	Amphibole
9	Ca-1058-1	"	"	Eclo-Amphibolite
	"	"	"	Garnet
	"	"	"	Pyroxene
	"	"	"	Amphibole
10	Ca-1115	"	"	Eclo-Amphibolite
	"	"	"	Garnet
	"	"	"	Pyroxene
	"	"	"	Amphibole
11	Ca 1215	"	"	Eclo-Amphibolite
12	Ca 1000P-16	"	"	Eclo-Amphibolite
	"	"	"	Garnet
	"	"	"	Amphibole
13	Ca 1000P-23	"	"	Eclo-Amphibolite
	"	"	"	Garnet

CODE USED IN TEXT	AUTHOR'S SAMPLE NUMBER	REFERENCE	LOCALITY	ROCK OR MINERAL TYPE
13	Ca 1000P-23	Morgan,B.A. 1967 Ph.D Thesis,Princeton	Venezuela	Amphibole
14	Ca 1059	"	"	Garnet
	"	"	"	Pyroxene
15	Ca 1000 X	"	"	Garnet
	"	"	"	Amphibole
16	Ca 1123	"	"	Amphibole
17	Ca 1067-1	"	"	Amphibole
18	-	Williams, A. F. 1932	Roberts-Victor	Eclogite
19	I	Banno, S and Yoshino, G.	Bessi	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
20	II	"	"	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
21	III	"	"	Garnet
	"	"	"	Pyroxene
	"	"	"	Amphibole
22	IV	"	"	Eclogite
	"	"	"	Garnet
23	V	"	"	Garnet
24	1	Kushiro, I and Aoki, K. 1968	Roberts-Victor	Eclogite
	"	"	"	Garnet

CODE USED IN TEXT	AUTHOR'S SAMPLE NUMBER	REFERENCE	LOCALITY	ROCK OR MINERAL TYPE
24	1	Kushiro, I and Aoki, K. 1968	Roberts-Victor	Pyroxene
25	2	"	"	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
26	3	"	"	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
27	4	"	"	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
29	5	"	"	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
30	6	"	"	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
31	1	Smulikowski, K. 1960	Bilice	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
32	4	"	Nowa Weis	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
33	2	"	Snieznik Mts.	Eclogite

CODE USED IN TEXT	AUTHOR'S SAMPLE NUMBER	REFERENCE	LOCALITY	ROCK OR MINERAL TYPE
33	2	Smulikowski, K. 1960	Snieznik Mts.	Eclogite
34	5	"	"	Eclogite
35	G-724	McBirney, A. et al. 1967	Manzanal	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
36	101757	Binns, R.A. 1967	Naustdal	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
	"	"	"	Amphibole
37	-	Eskola, P. 1921	Duen	Eclogite
		"	"	Garnet
		"	"	Pyroxene
38	KA646	Williams, A.F. 1932	Roberts-Victor	Eclogite
	"	"	"	Pyroxene
39	1	Fiala, J. 1966	Skelene	Garnet-Peridotite
	"	"	"	Garnet
	"	"	"	Pyroxene
40	2	"	Hulabor	Garnet-Peridotite
	"	"	"	Garnet
	"	"	"	Pyroxene
41	A2	"	Switzerland	Garnet
	"	"	"	Pyroxene

CODE USED IN TEXT	AUTHOR'S SAMPLE NUMBER	REFERENCE	LOCALITY	ROCK OR MINERAL TYPE
42	A3	Fiala, J. 1966	Wesselton	Garnet
	"	"	"	Pyroxene
43	N69	"	Almklovdalen	Garnet
	"	"	"	Pyroxene
44	N70	"	Norway	Garnet
	"	"	"	Pyroxene
45	1902	Lovering, J. F. 1964	Ruby Hill	Garnet Granulite
		"	"	Pyroxene
46	R169	"	"	Eclogite
47	R165	"	"	Garnet Granulite
48	"	"	"	Garnet
49	"	O'Hara, M.F. and Mercy, ELP 1966	Garnet Ridge	Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
50	665	"	"	Garnet
51	666	"	"	Garnet
52	668	"	Arizona	Garnet
53	GK6	"	Green Knob	Garnet
	"	"	"	Pyroxene
54	GK3	"	"	Pyroxene
63	V1234	Vogel, D.E. 1967	Cabo Ortegal	Garnet
	"	"	"	Pyroxene

CODE USED IN TEXT	AUTHOR'S SAMPLE NUMBER	REFERENCE	LOCALITY	ROCK OR MINERAL TYPE
64	V1023	Vogel, D.E. 1967	Cabo Ortegal	Garnet
	"	"	"	Pyroxene
	"	"	"	Amphibole
65	V1278	"	"	Garnet
	"	"	"	Pyroxene
66	V1050	"	"	Garnet
	"	"	"	Pyroxene
67	M459	"	"	Garnet
	"	"	"	Pyroxene
68	M616	"	"	Garnet
69	G1-16	"	"	Garnet
100		Banno, S. 1967	Yakutia	Garnet
		"	"	Pyroxene
101		"	Roberts-Victor	Garnet
		"	"	Pyroxene
102	456	"	Silber Bach	Garnet
	"	"	"	Pyroxene
104	330	"	"	Garnet
	"	"	"	Pyroxene
120	"	Phillipsborn, H. 1920	Granulitgerirge	Garnet
		"	"	Pyroxene
184		Williams, A.F. 1932	Roberts-Victor	Average Eclogite

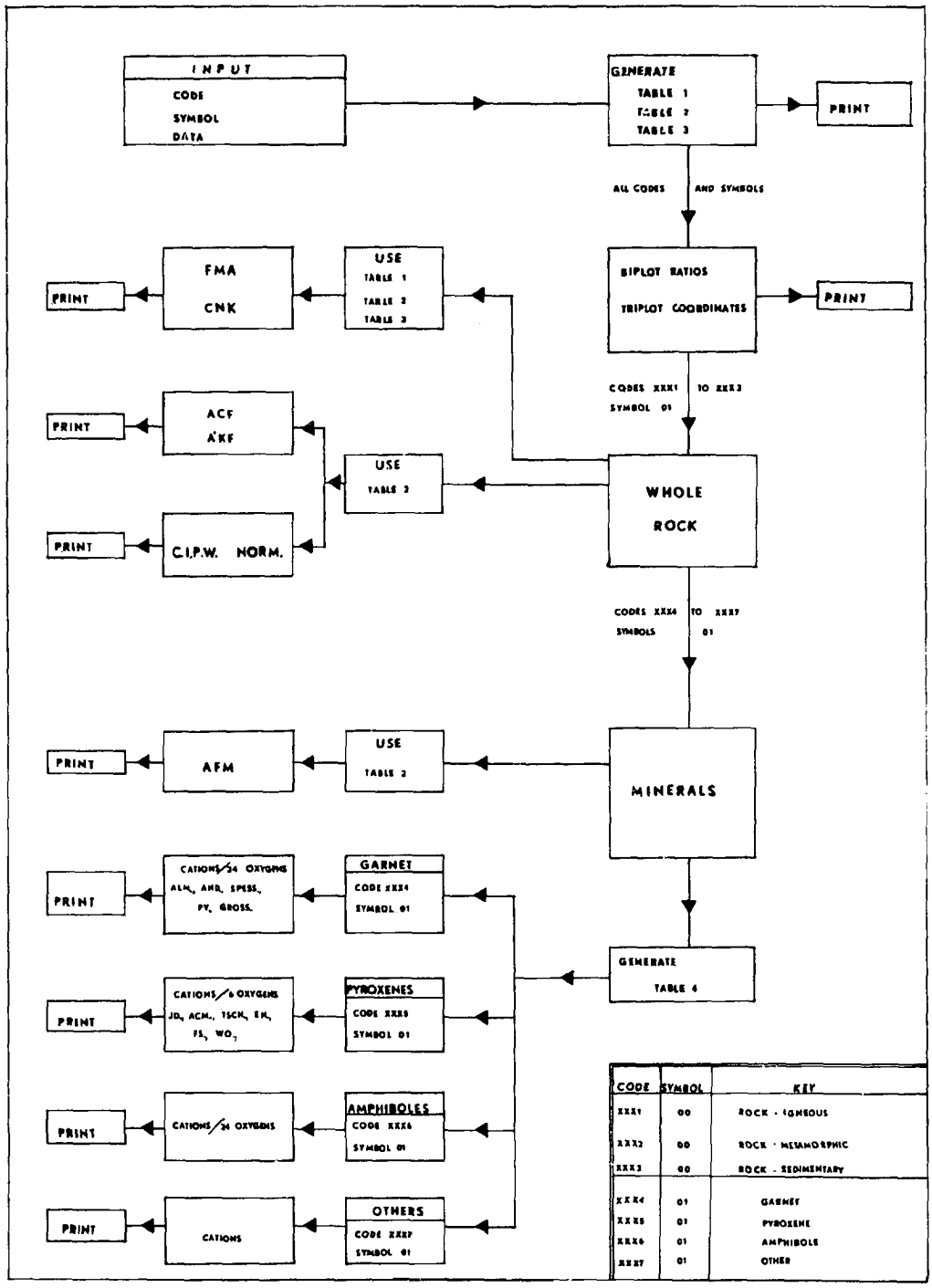
CODE USED IN TEXT	AUTHOR'S SAMPLE NUMBER	REFERENCE	LOCALITY	ROCK OR MINERAL TYPE
193		Coleman, R.G., Papike, J.J. 1968	California	Crossite
194		"	"	"
195		"	"	"
196		"	"	"
198		"	"	Glaucophane
199		"	"	"
200		"	"	"
201		"	"	"
202		"	"	"
203		"	"	"
204		"	"	"
205		"	"	"
206		Koritnig, S. 1940	Saualpe	Amphibole
207		Heritsch, H. and Kahler, E. 1960	Kupplerbrun	"
F229	ECDD 12A	This Report	Fairbanks	Amphibolite
F230		"	"	Garnet Amphibolite
F231		"	"	Eclogite
234	II	Yoder, H.S. and Tilley, C.E. 1962	Loch Duich	Eclogite
239	M541	Essene, E. J., 1967	South Berkeley	Garnet Pyroxene Rock
F10	10	This paper	Fairbanks	Schist
F11	11	"	"	Schist
F29	29	"	"	Schist
F39	39	"	"	Eclogite

CODE USED IN TEXT	AUTHOR'S SAMPLE NUMBER	REFERENCE	LOCALITY	ROCK OR MINERAL TYPE
F39	39	This paper	Fairbanks	Garnet
	39	"	"	Pyroxene
F50	50	"	"	Eclo-Amphibolite
	"	"	"	Garnet
	"	"	"	Pyroxene
	"	"	"	Amphibole
	"	"	"	Mica
F70	70	"	"	Garnet
F71	71	"	"	Schist
	"	"	"	Garnet
F75	75	"	"	Garnet
	"	"	"	Pyroxene
F78	78	"	"	Garnet
	"	"	"	Pyroxene
F80	80	"	"	Garnet
	"	"	"	Pyroxene
F86	86	"	"	Amphibole Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
	"	"	"	Amphibole
F89	89	"	"	Eclo-Amphibolite
	"	"	"	Garnet

CODE USED IN TEXT	AUTHOR'S SAMPLE NUMBER	REFERENCE	LOCALITY	ROCK OR MINERAL TYPE
F89	89	This report	Fairbanks	Pyroxene
	"	"	"	Amphibole
F92	92	"	"	Garnet
	"	"	"	Pyroxene
F93	93	"	"	Garnet
	"	"	"	Pyroxene
F99	99	"	"	Garnet
	"	"	"	Pyroxene
F100	100	"	"	Garnet
	"	"	"	Pyroxene
F101	101	"	"	Amphibole-Eclogite
	"	"	"	Garnet
	"	"	"	Pyroxene
F136	136	"	"	Garnet-Amphibolite
	"	"	"	Garnet
	"	"	"	Amphibole
	"	"	"	Mica
F162	162	"	"	Amphibolite
F201	201	"	"	Amphibole-Eclogite
				Garnet
				Pyroxene

APPENDIX #3

A COMPUTER PROGRAM FOR CALCULATING PETROCHEMICAL DATA FROM THE CHEMICAL ANALYSES OF ROCKS AND MINERALS.



COMMON TABLES

TABLE #2 Molecular Proportions, Derived from Table #1	TABLE #1 Wt. % Oxide, From chemical analysis.	TABLE #3 Cation Ratios, Derived from Table #1
SiO2 /60.09	SiO_2	SiO_2 x 0.4675
TiO_2 /79.90	TiO_2	TiO_2 x 0.5995
Al_2O_3 /101.96	Al_2O_3	Al_2O_3 x 0.2637
Fe_2O_3 /159.70	Fe_2O_3	Fe_2O_3 x 0.3497
FeO /71.85	FeO	FeO x 0.7773
MnO /70.94	MnO	MnO x 0.7745
MgO /40.32	MgO	MgO x 0.6023
CaO /56.08	CaO	CaO x 0.7147
Na_2O /61.98	Na_2O	Na_2O x 0.3709
K_2O /94.20	K_2O	K_2O x 0.4151
P_2O_5 /141.94	H_2O^+	
H_2O^+ /18.00	H_2O^-	
H_2O^- /18.00	Cr_2O_3	
	NiO	
	CO_2	

BIPLOT AND TRIPLOT RATIOS

(All expressed in terms of the Tables 1,2 and 3.)

BIPLOTS.

MgO: (MgO + FeO)

MgO: FeO

CaO: MgO

Fe_2O_3: FeO

Fe_2O_3: (FeO + Fe_2O_3)

MgO: (MgO + CaO)

Fe_2O_3: (Fe_2O_3 + FeO + MnO)

(Fe_2O_3+FeO+MnO): (Fe_2O_3 + FeO + MnO + MgO)

TRIPLOTS.

Al_2O_3: CaO: Na_2O

K_2O: CaO: Na_2O

Al_2O_3: MgO: FeO

Al_2O_3: CaO: (FeO + MnO)

CaO: MgO: (FeO + MgO)

(Na_2O + K_2O): MgO: (FeO + Fe_2O_3)

Recalculate to 100%, i.e.

X:Y:Z

X+Y+Z=W.

Then X^t = (100/W) X

Y^t = (100/W) Y

Z^t = (100/W) Z

WHOLE ROCK CALCULATIONS

F.M.A. ----- Derived from tables #1, 2 and 3.

$F = (FeO + MnO)$

$M = MgO$ Recalculated to 100%.

$A = (Na_2O + K_2O)$

C.N.K. ----- Derived from tables #1, 2 and 3.

$C = CaO$

$N = Na_2O$ Recalculated to 100%.

$K = K_2O$

Approximate A.C.F. --Derived from table #2.

$A = (Al_2O_3 + Fe_2O_3) - (Na_2O + K_2O)$

$C = CaO$ Recalculated to 100%

$F = (FeO + MgO + MnO)$

Approximate A.K.F. --Derived from table #2.

$A = (Al_2O_3 + Fe_2O_3) - (CaO + Na_2O + K_2O)$

$K = K_2O$

$F = (FeO + MnO + MgO)$

C.I.P.W. Normative Analysis.---Derived from table #2.

MINERAL CALCULATIONS

THOMPSON'S A.F.M.

$A = (Al_2O_3 - 3K_2O) / (Al_2O_3 - 3K_2O + FeO + MnO)$

$F = FeO$

$M = (MgO / MgO + FeO)$

Recalculate to 100%

GENERATE TABLE #4 FROM TABLE #2.

TABLE #2

Molecular Proportions

SiO_2	/60.09
TiO_2	/79.90
Al_2O_3	/101.96
Fe_2O_3	/159.70
FeO	/71.85
MnO	/70.94
MgO	/40.32
CaO	/56.08
Na_2O	/61.98
K_2O	/94.20
P_2O_5	/141.94
P_2O_5	/141.94
H_2O^+	/18.00
H_2O^-	/18.00

TABLE #4

Atom Proportions of oxygen/mol.

Table 2 value x 2.0
" x 2.0
" x 3.0
" x 3.0
" x 1.0
" x 1.0
" x 1.0
" x 1.0
" x 1.0
" x 1.0
" x 1.0
" x 1.0
" x 1.0
" x 1.0

TOTAL = Q, USED TO GENERATE TABLES #5

GARNET CALCULATIONS

$24/Q = Y$

TABLE # 5, DERIVED FROM TABLE #4

Anions per formula unit on the basis of 24 oxygen atoms.

Si^{++++}	=	Table #4 value	x Y/2
Ti^{++++}	=	"	x Y/2
Al^{+++}	=	"	x 2Y/3
Fe^{+++}	=	"	x 2Y/3
Fe^{++}	=	"	x Y
Mn^{++}	=	"	x Y
Mg^{++}	=	"	x Y
Ca^{++}	=	"	x Y
Na^{+}	=	"	x 2Y
K^{+}	=	"	x 2Y
H^{+}	=	"	x 2Y

$6.000 - Si^{++++} = Al^{IV}$

$Al^{+++} - Al^{IV} = Al^{VI}$

GARNET CALCULATIONS (Cont.)

TABLE #6 (Print)

Si^{++++}

Al^{IV}

Al^{VI}

Fe^{+++}

Ti^{++++}

Mg^{++}

Fe^{++}

Mn^{++}

Ca^{++}

End-member calculation.

1) ALMANDINE Let Fe^{++} = 3 units. then ALM! = Fe^{++} + 2 units Al^{VI} + 3 units Si^{++++}

2) ANDRADITE Let Fe^{+++} = 2 units then AND! = Fe^{+++} = 3 units Ca^{++} + 3 units Si^{++++}

3) GROSSULAR Let remining Ca^{++} = 3 units then GRO! = Ca^{++} + 2 units Al^{VI} + 3 units Si^{++++}

4) PYROPE Let Mg^{++} = 3 units then PYR! = Mg^{++} + 2 units Al^{VI} + 3 units Si^{++++}

5) SPESSARTINE Let Mn^{++} + 3 units. then SPESS!= Mn^{++} + 2 units Al^{VI} + 3 units Si^{++++}

Recalculate to 100% and print out.

PYROXENE CALCULATION

$6/Q = Y$

TABLE #5, DERIVED FROM TABLE #4

anions per formula unit on the basis of 6 oxygen atoms.

Si^{++++} = Table #4 value x $Y/2$

Ti^{++++} = " x $Y/2$

Al^{+++} = " x $2Y/3$

Fe^{+++} = " x $2Y/3$

Fe^{++} = " x Y

Mn^{++} = " x Y

Mg^{++} = " x Y

Ca^{++} = " x Y

Na^{+} = " x $2Y$

K^{+} = " x $2Y$

H^{+} = " x $2Y$

$2.000 - Si^{++++} = Al^{1V}$

$Al^{+++} - Al^{1V} = Al^{V1}$

Print out TABLE #6

Si^{++++}

Al^{1V}

Al^{V1} Mn^{++}

Fe^{+++} Ti^{++++}

Fe^{++} Mg^{++}

Ca^{++} Na^{+} K^{+}

PYROXENE CALCULATIONS, (Cont.)

End-member calculation.

1) ACMITE.

a) If Fe^{+++} is less than Na^{+}

Let Fe^{+++} = 1 unit.

Then AC. = Fe^{+++} + 1 unit Na^{+} + 2 units Si^{++++}

b) If Na^{+} is less than Fe^{+++}.

Then AC. = Na^{+} + 1 unit Fe^{+++} + 2 units Si^{++++}

2) JADEITE.

Let K^{+} + remaining Na^{+} = 1 unit.

Then JD. = (K^{+} + Na^{+})+ 1 unit Al^{VI} + 2 units Si^{++++}

3) TSCHERMAK'S.

Let Al^{IV} + remaining Fe^{+++} = 1 unit.

Then TSCH. = (Al^{IV} + Fe^{+++}) + 1 unit Mg^{++}

+ 1 unit Al^{VI} + 1 unit Si^{++++}

4) FERROSILITE.

Let (Mn^{++} + Fe^{++}) = 1 unit.

Then FS. = (Mn^{++} + Fe^{++}) + 1 unit Si^{++++}

5) ENSTATITE.

Let remaining Mg^{++} = 1 unit.

Then ENST. = Mg^{++} + 1 unit Si^{++++}

6) WOLLASTONITE.

Let Ca^{++} = 1 unit.

Then WOLL. = Ca^{++} + 1 unit Si^{++++}

Recalculate to 100 % and print out.

N.B. DIOPSIDE = 1 ENST. + 1 WOLL.

HEDENBERGITE = RESIDUAL WOLL + EQUAL AMOUNT FS.

AMPHIBOLE CALCULATIONS.

$24/Q = Y$

TABLE #5, DERIVED FROM TABLE #4.

Anions per formula unit on the basis of 24 oxygen atoms.

Si^{++++} = Table #4 value x Y/2

Ti^{++++} = " x Y/2

Al^{+++} = " x 2Y/3

Fe^{+++} = " x 2Y/3

Fe^{++} = " x Y

Mn^{++} = " x Y

Mg^{++} = " x Y

Ca^{++} = " x Y

Na^{+} = " x 2Y

K^{+} = " x 2Y

H^{+} = " x 2Y

$8.000 - Si^{++++} = Al^{1V}$

$Al^{+++} - Al^{1V} = Al^{V1}$

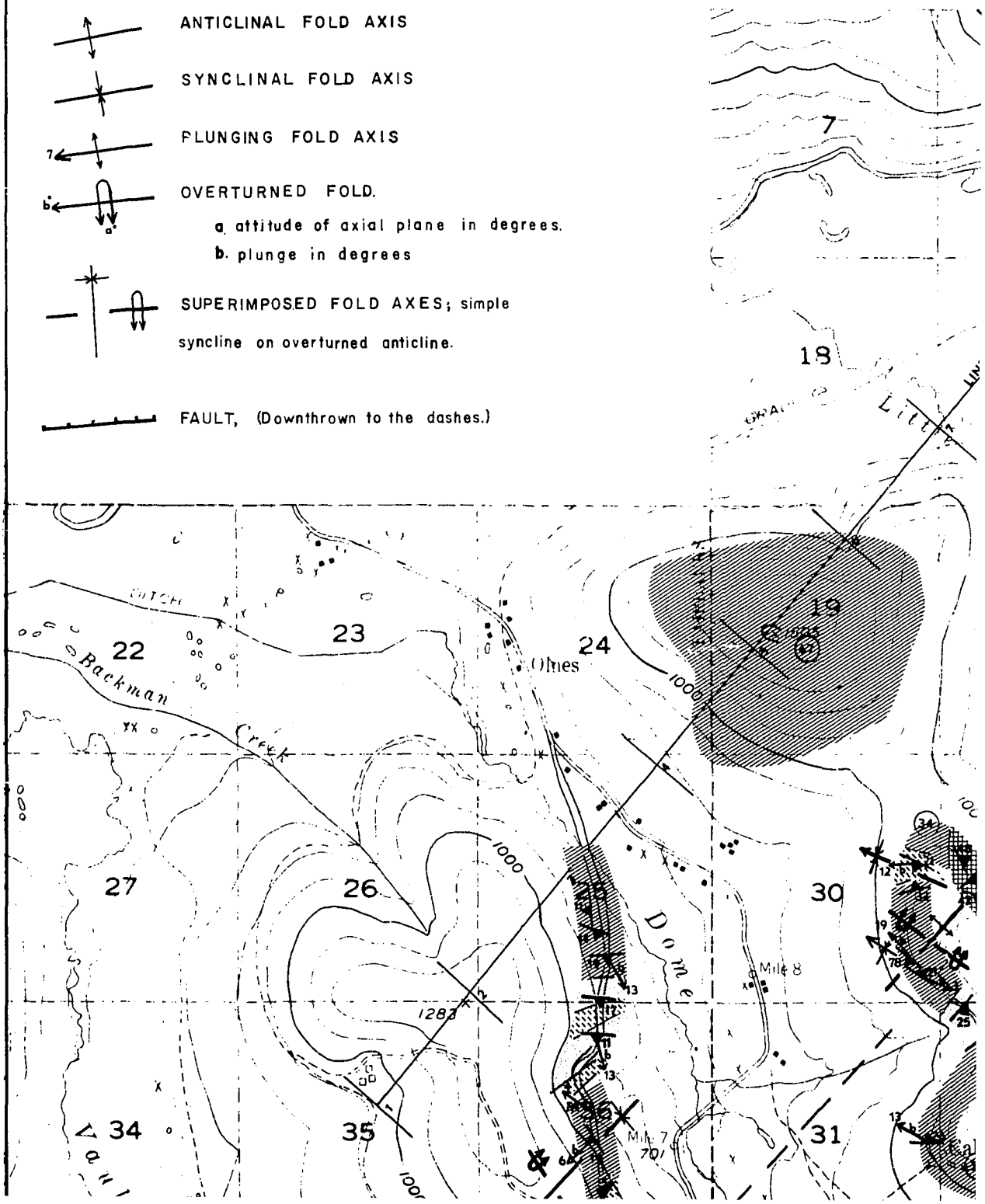
Print out TABLE #6

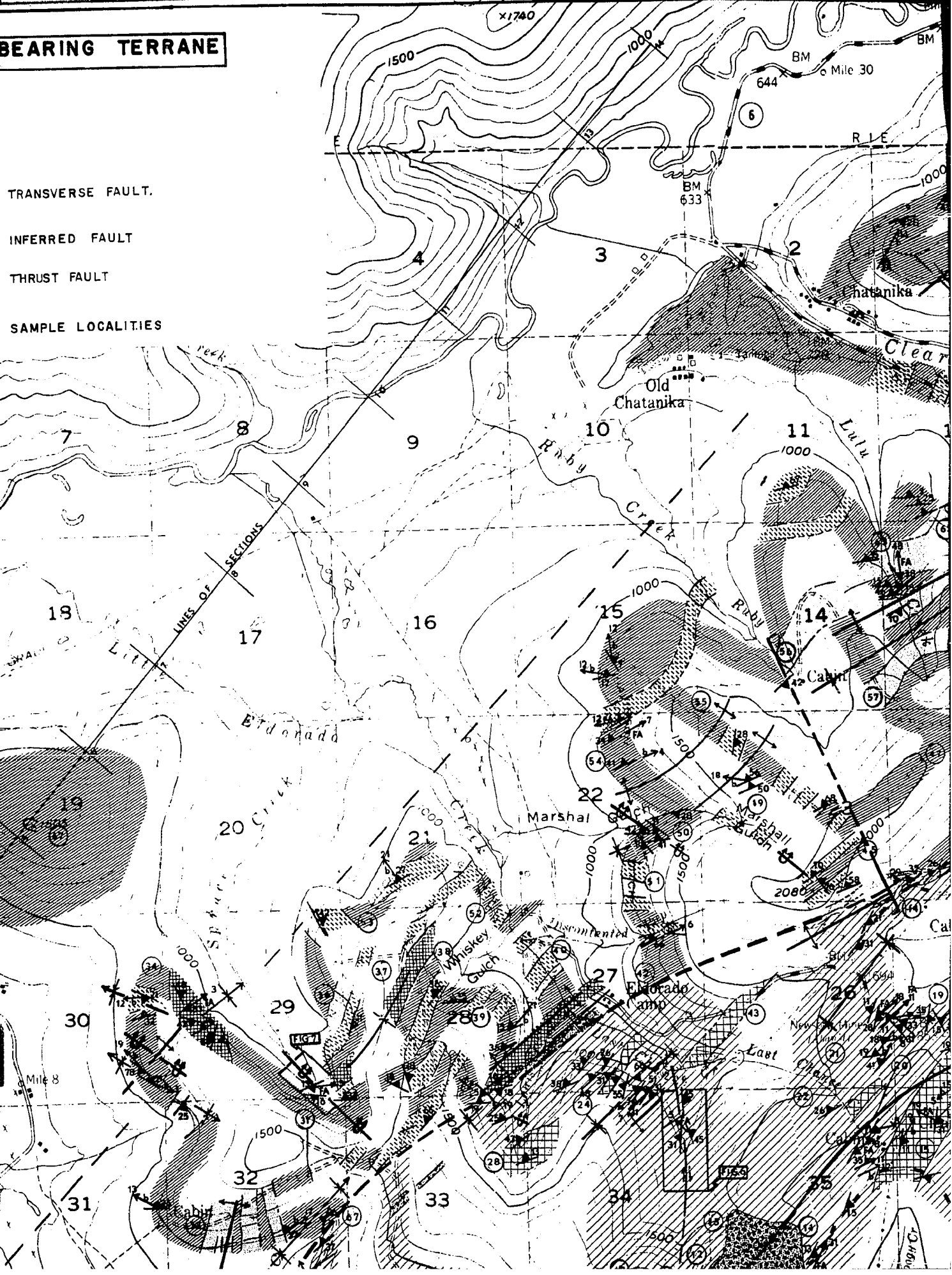
Si^{++++}	Al^{V1}	Na^{+}	H^{+}
Al^{1V}	Fe^{+++}	K^{+}	
	Fe^{++}	Ca^{++}	
	Mn^{++}		
	Mg^{++}		

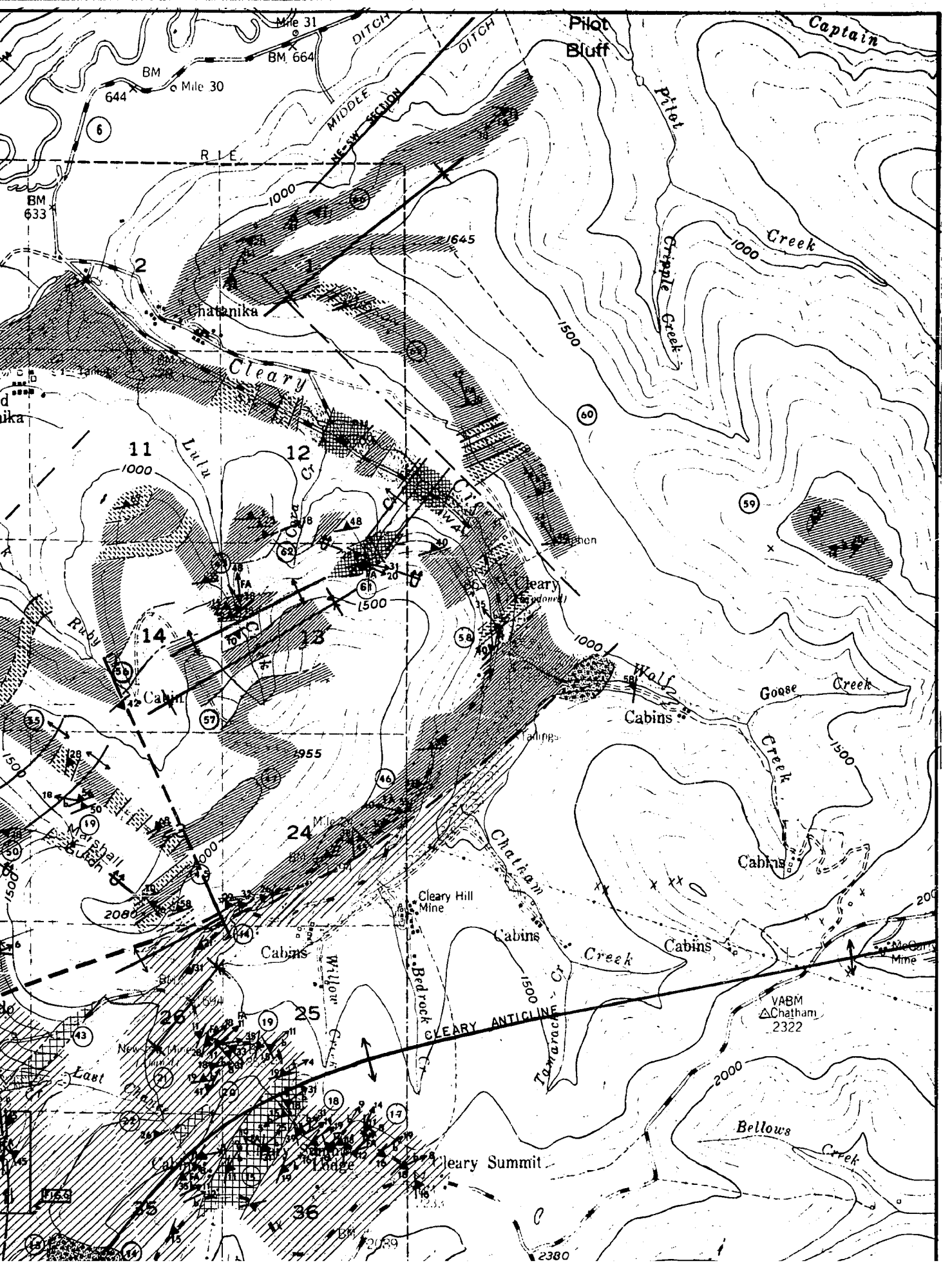
BEDROCK GEOLOGY OF THE ECLOGITE-BEARING TERR
NORTH OF FAIRBANKS, ALASKA.

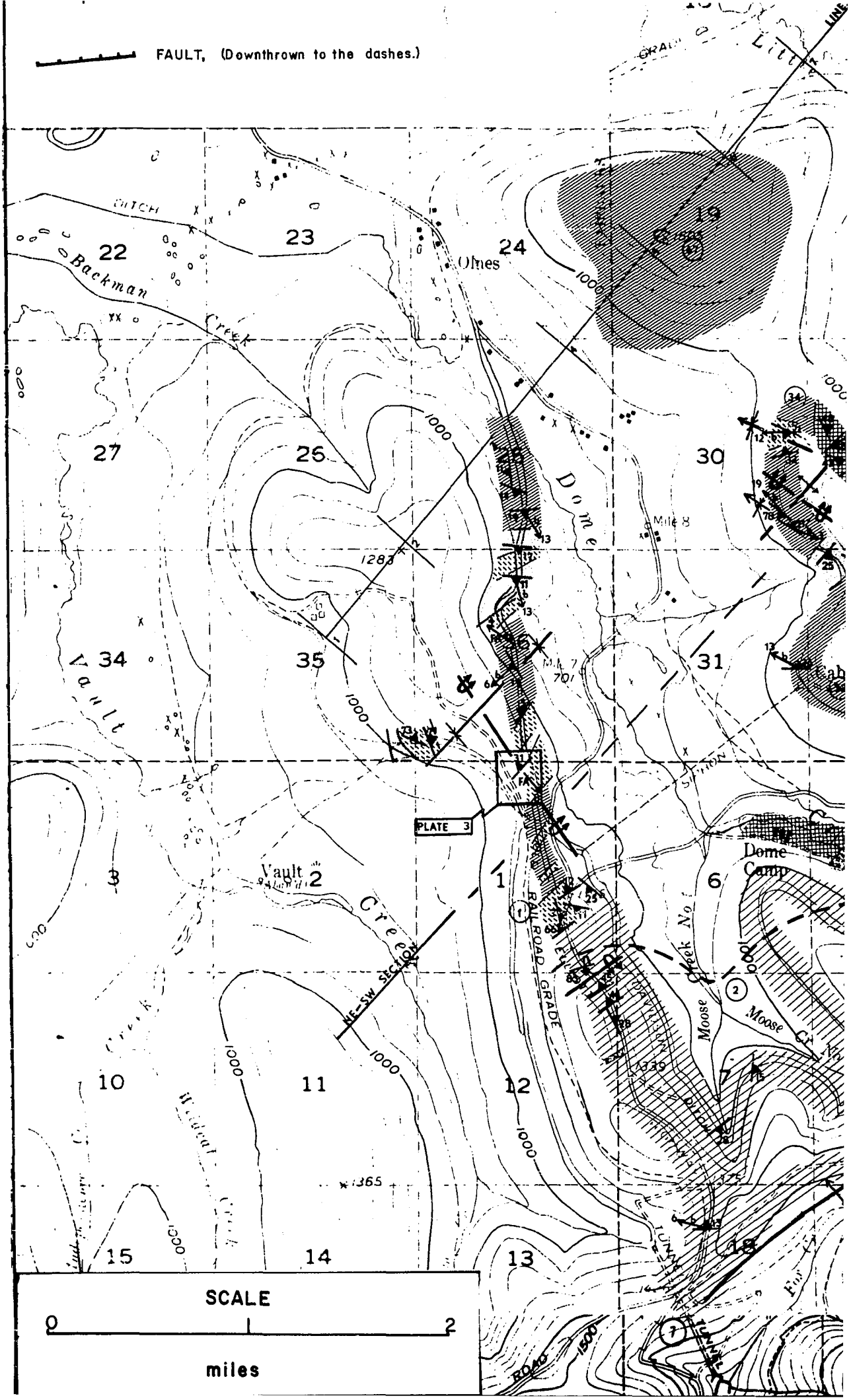
SYMBOLS

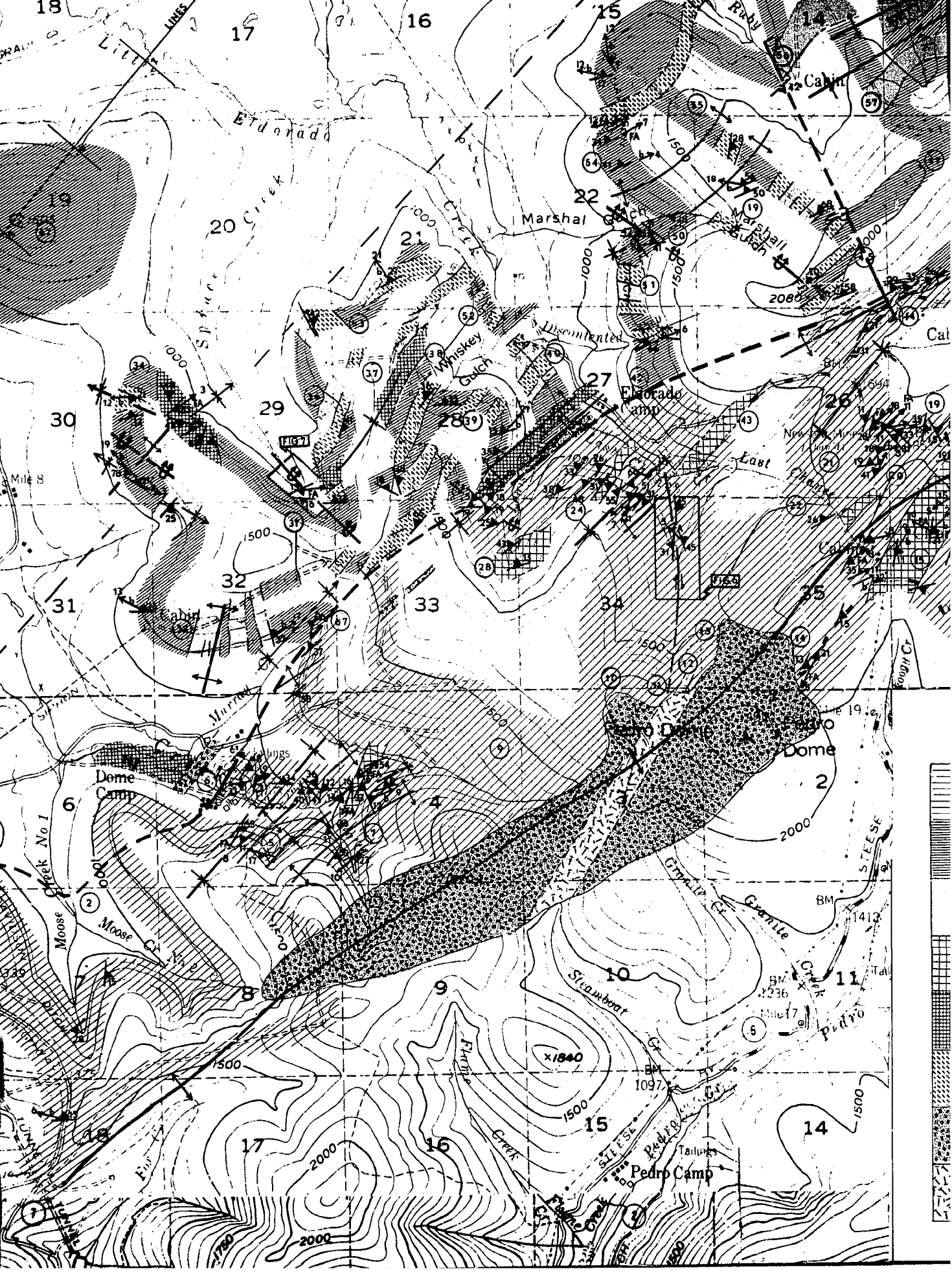
- FOLIATION
- OVERTURNED FOLIATION.
- FOLD AXES, (Plunge in degrees)
- b LINEATION. (Dip in degrees.)
- ANTICLINAL FOLD AXIS
- SYNCLINAL FOLD AXIS
- PLUNGING FOLD AXIS
- OVERTURNED FOLD.
  - a. attitude of axial plane in degrees.
  - b. plunge in degrees
- SUPERIMPOSED FOLD AXES; simple syncline on overturned anticline.
- FAULT, (Downthrown to the dashes.)
- TRANSVERSE FAULT.
- INFERRED FAULT
- THRUST FAULT
- SAMPLE LOCALITIES

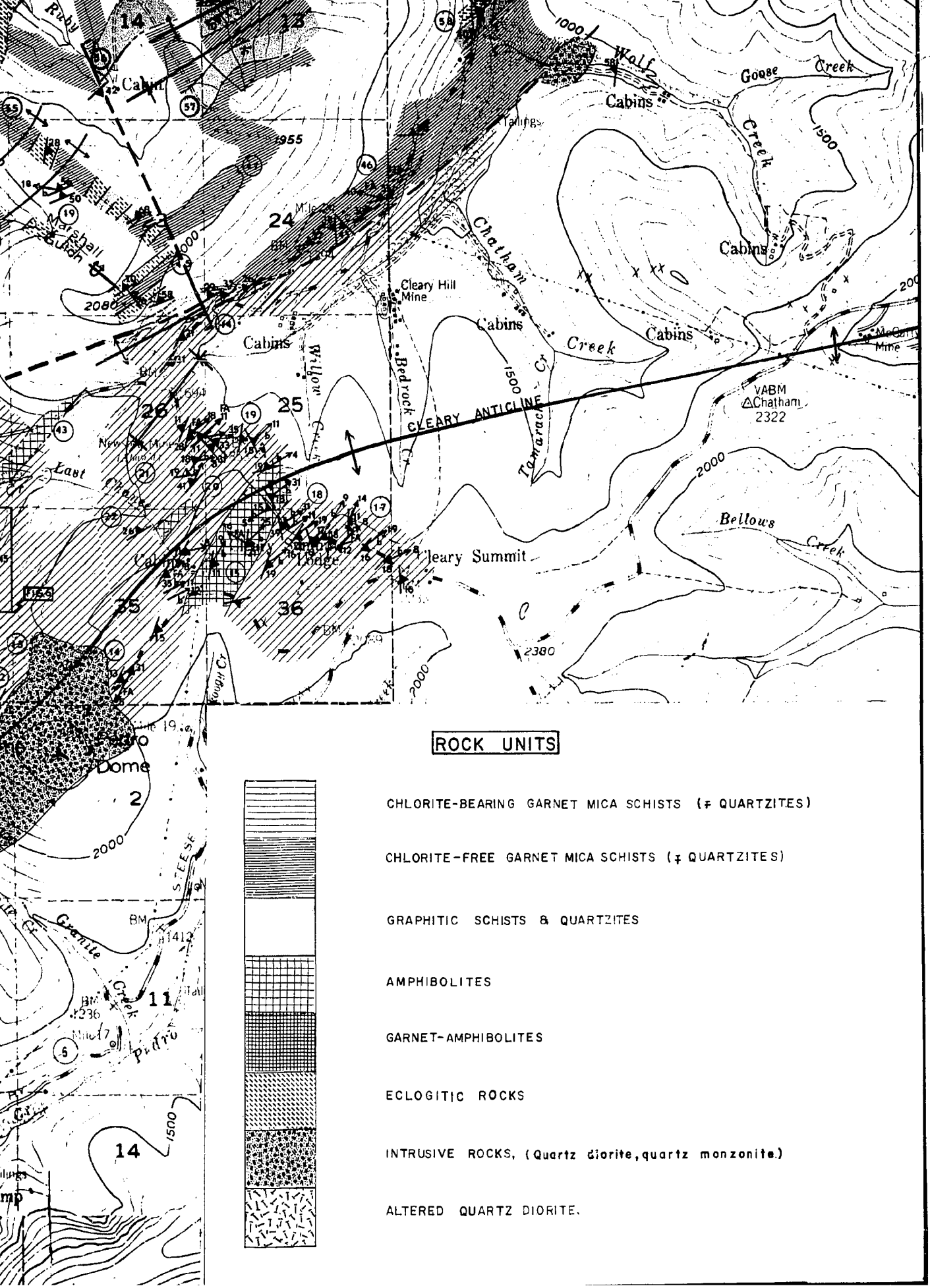












ROCK UNITS

CHLORITE-BEARING GARNET MICA SCHISTS (∓ QUARTZITES)

CHLORITE-FREE GARNET MICA SCHISTS (∓ QUARTZITES)

GRAPHITIC SCHISTS & QUARTZITES

AMPHIBOLITES

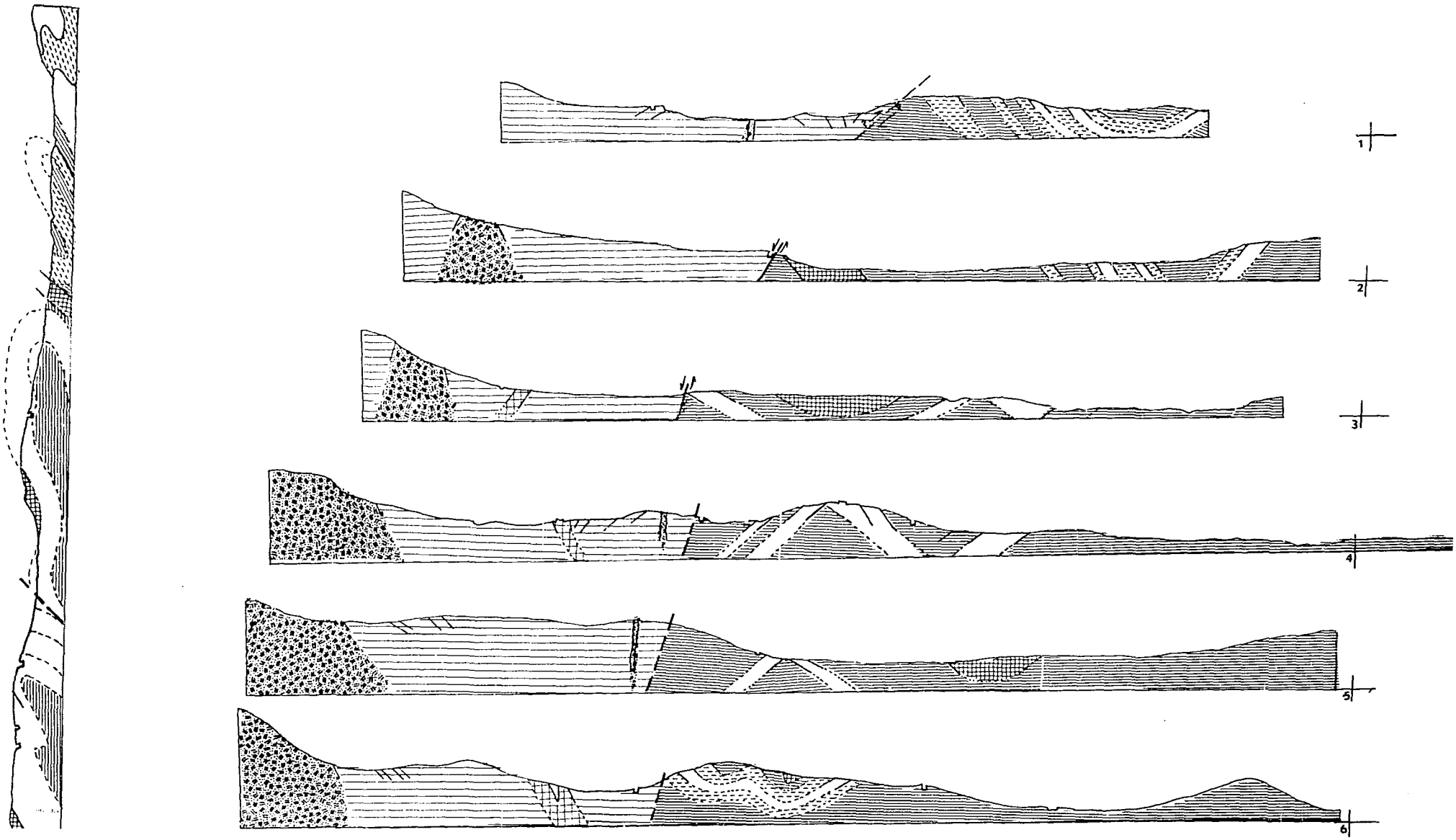
GARNET-AMPHIBOLITES

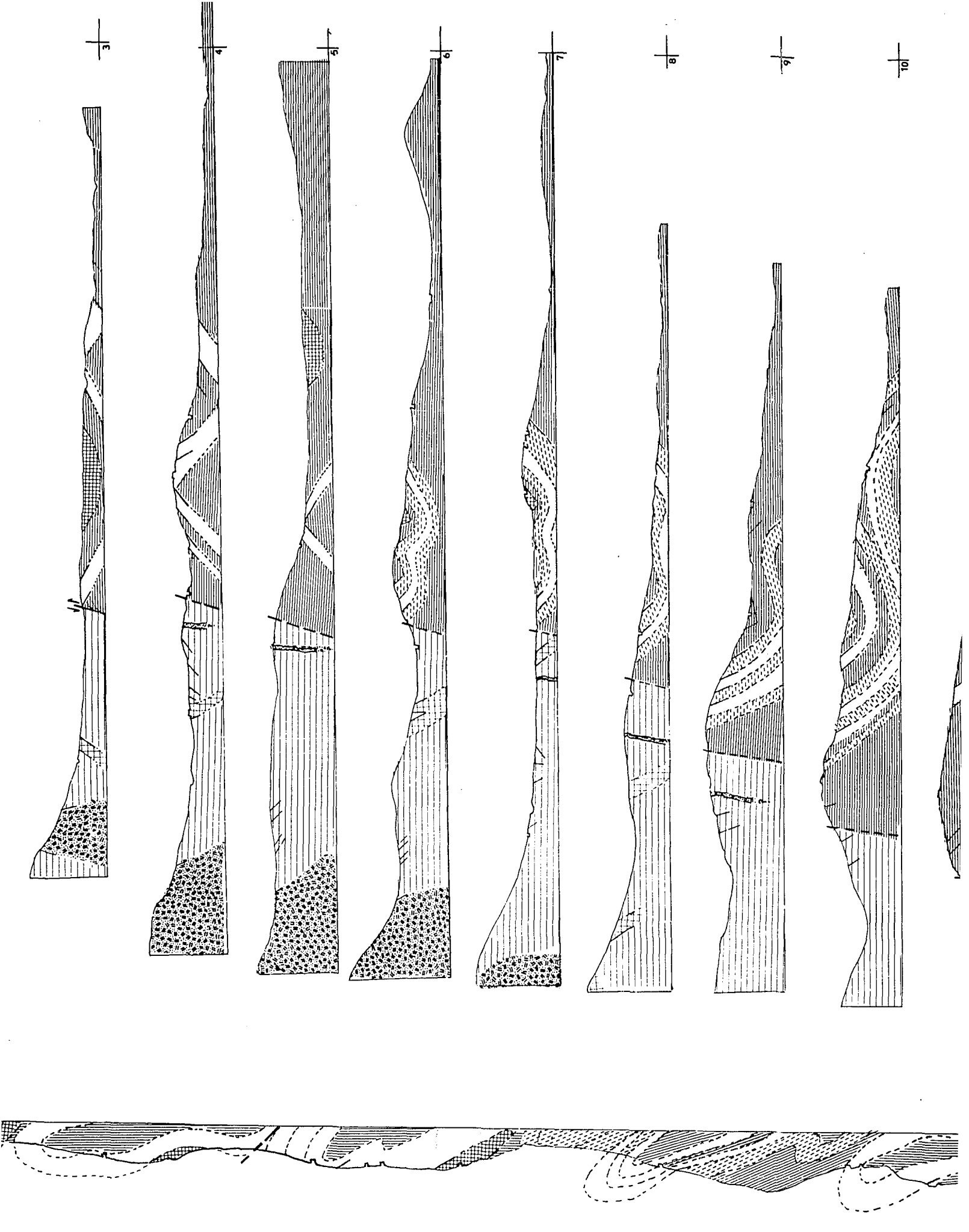
ECLOGITIC ROCKS

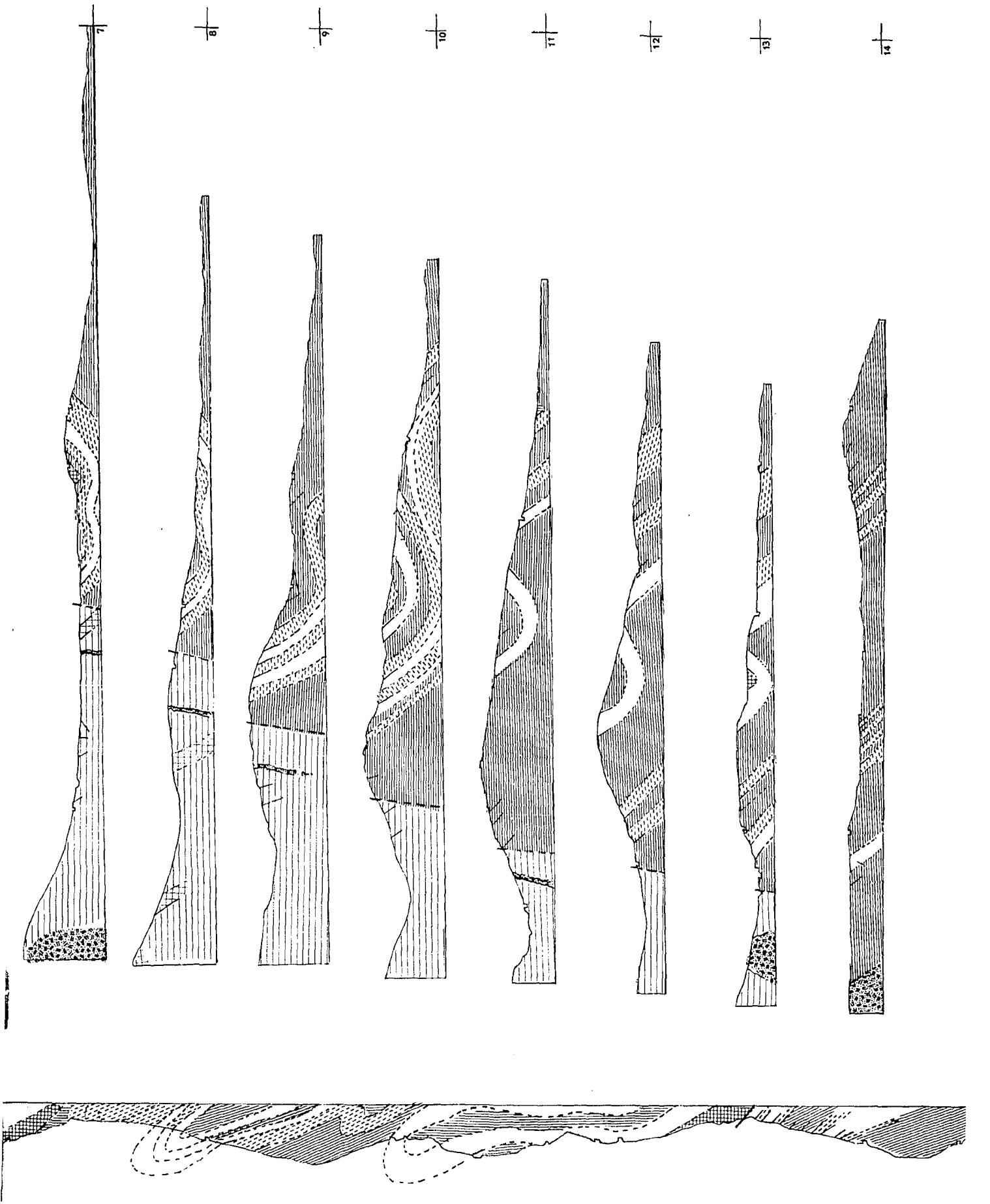
INTRUSIVE ROCKS, (Quartz diorite, quartz monzonite.)

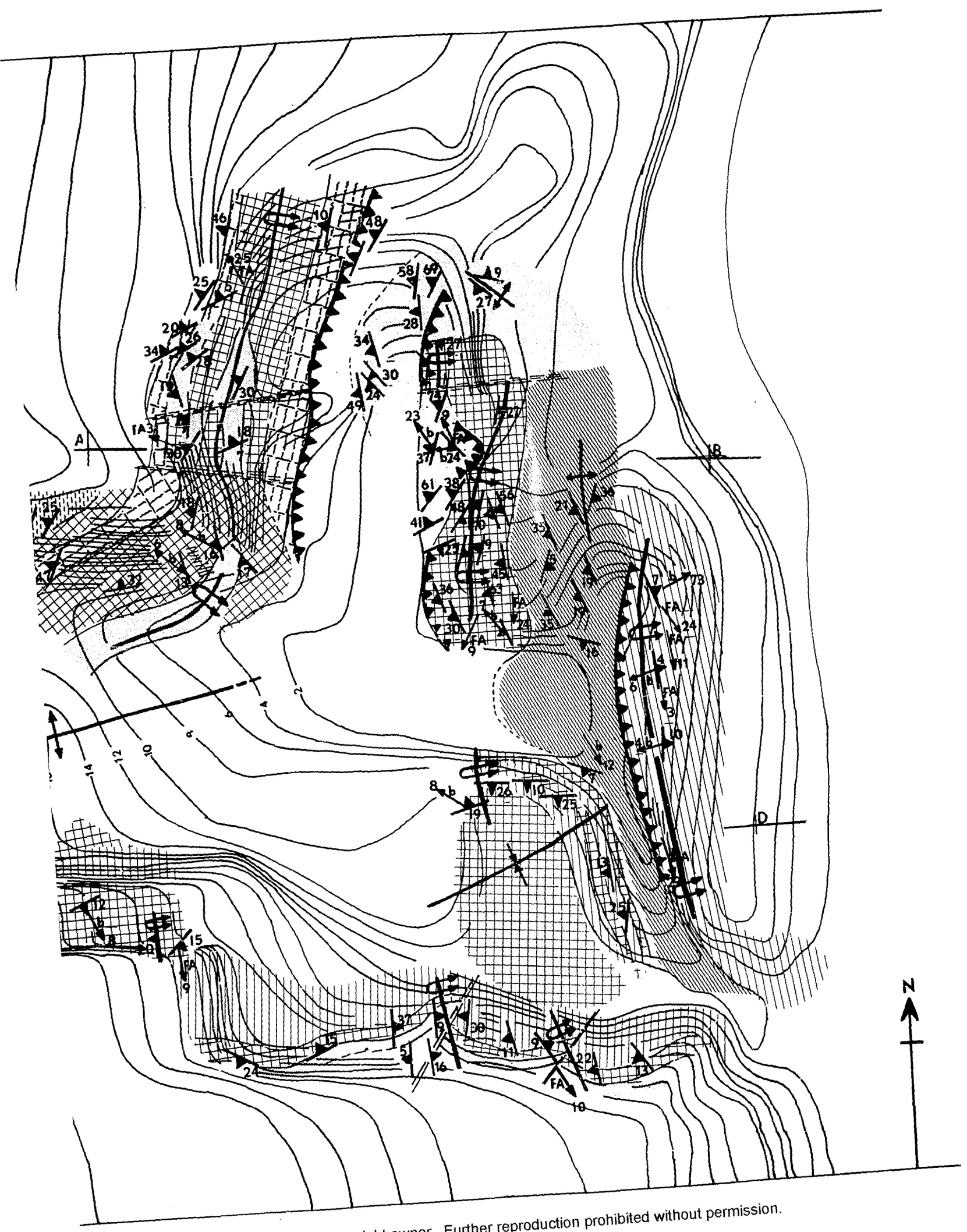
ALTERED QUARTZ DIORITE.

STRUCTURE SECTIONS IN THE ECLOGITE-BEARING TERRANE.









BEDROCK GEOLOGY

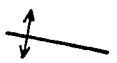
BORROW-PIT, 6·1 ml. Elliot Highway, Fairbanks, Alaska.

CONTOURS AT 2 FT. INTERVALS.

FOLIATION

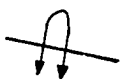
MINERAL LINEATION,

FOLD AXIS



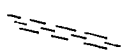
ANTICLINAL AXIS

SYNCLINAL AXIS



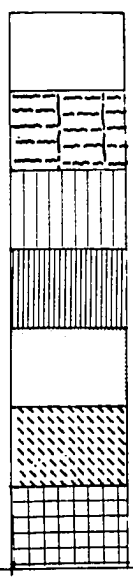
OVERTURNED FOLD AXIS

SUPERIMPOSED ANTICLINAL AXIS



FAULT ZONE

THRUST FAULT, ARROWS INDICATE DIP



Alluvium

Coarse grained garnet-mica schist

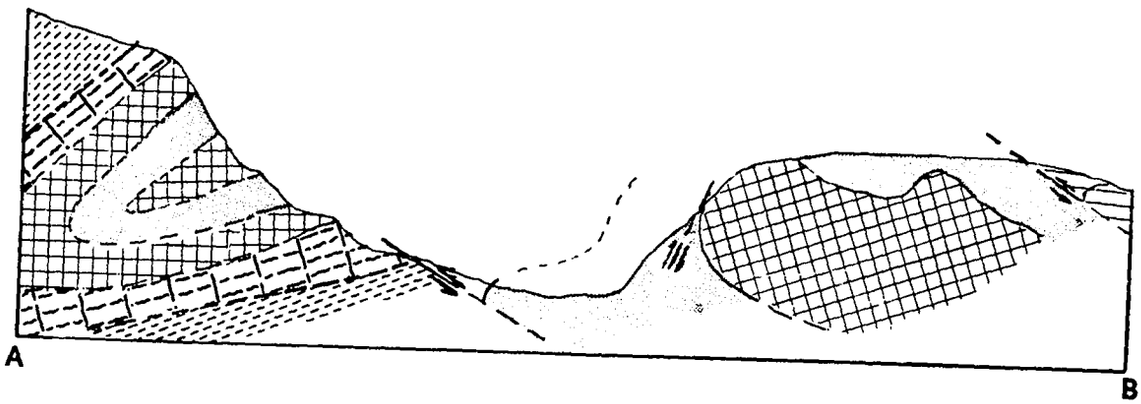
Garnet-mica schist

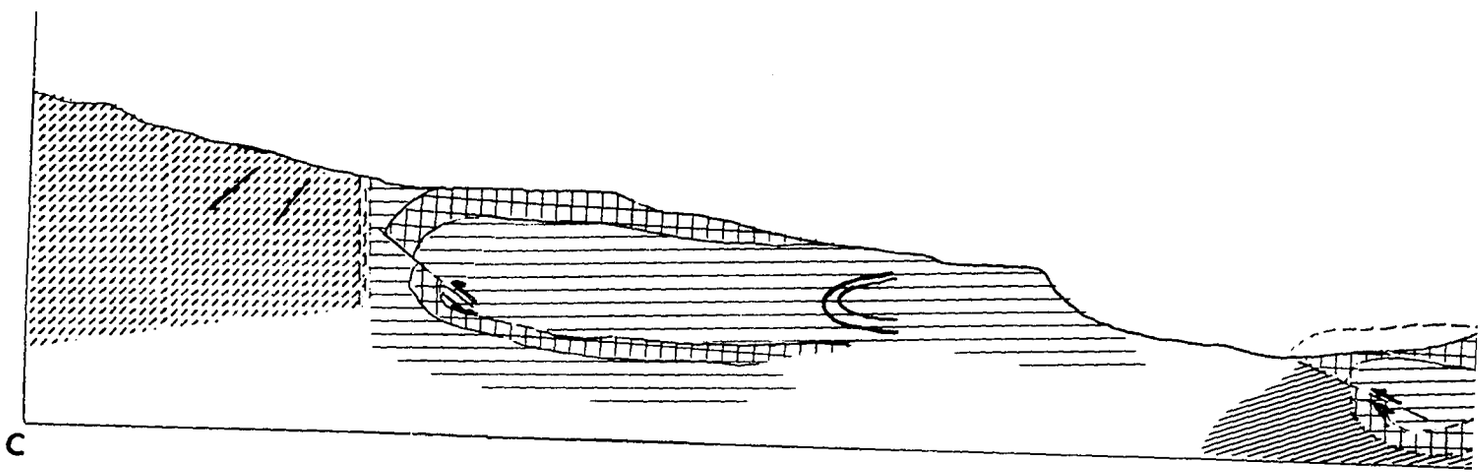
Graphitic schists

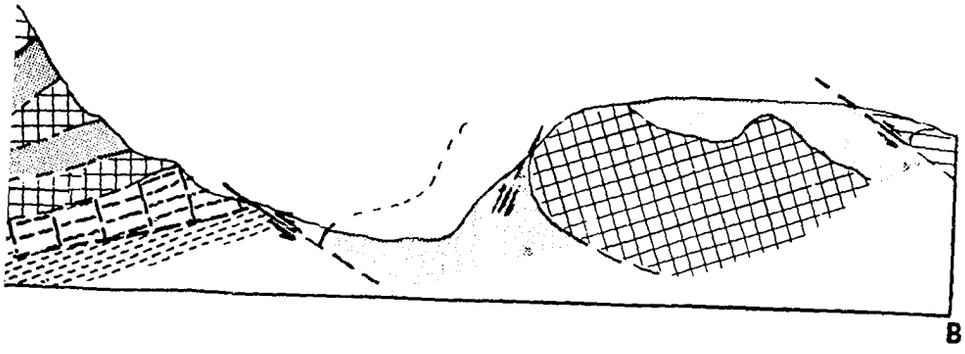
Graphitic quartzites

Epidote schist

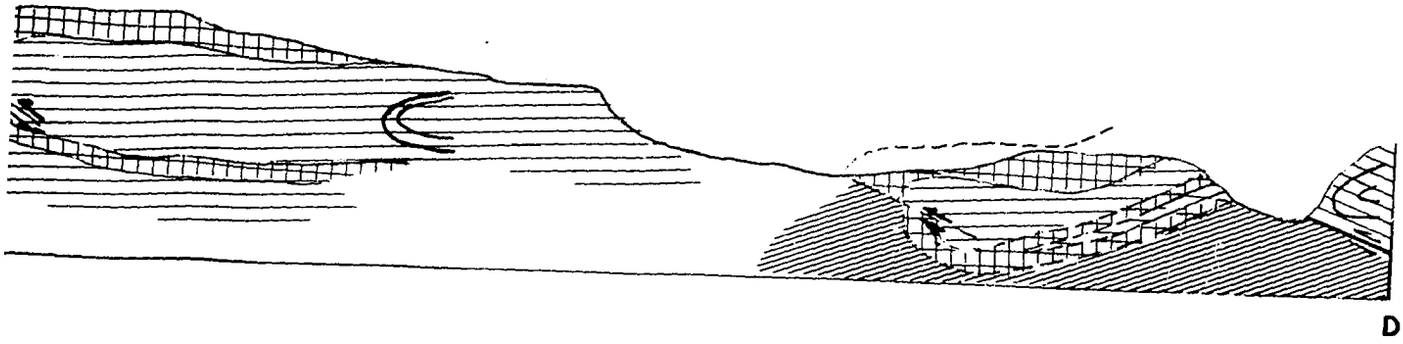
Eclogitic rocks







B



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